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Analysis of Control Strategies and Compliance Schedules for Wood Particle and Fiber Dryers

PEDCo-Environmental, Inc, Cincinnati, Ohio

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The state of the art of technology for control of emissions from wood particle and fiber dryers has been summarized and the status of compliance for such installations in the United States defined. Operational aspects of wood and fiber panel production are discussed. Pollutant emissions from dryer systems are characterized and emission measurement techniques are reviewed. For each major control option, the degree of success achieved in meeting regulations, major problems, approximate costs, and recommended applications are summarized. It has been concluded that particle dryers can be operated in compliance with most regulations, particularly those related to concentration, mass emission rates, and opacity, although no control system is universally applicable.

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Stationary Source Enforcement Series

ANALYSIS OF CONTROL STRATEGIES AND COMPLIANCE SCHEDULES FOR WOOD PARTICLE AND FIBER DRYERS

U.S. ENVIRONMENTAL PROTECTION AGENCY
Office Of Enforcement
Office of General Enforcement
Washington, D.C. 20460

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ANALYSIS OF CONTROL STRATEGIES AND COMPLIANCE SCHEDULES FOR WOOD PARTICLE AND FIBER DRYERS

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Portland, Oregon

July 1976

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1. INTRODUCTION

Under Section 113 of the Clean Air Act, as amended in 1970, the Administrator of the Environmental Protection Agency (EPA) is required to initiate Federal Enforcement Action against sources known to be in violation of any control strategy provisions of a State Implementation Plan (SIP). The EPA Regional Offices have primary responsibility for implementation of the Federal Enforcement Program. Policy development and guidance with respect to enforcement is furnished by EPA's Division of Stationary Source Enforcement. This report is concerned with control of pollutant emissions from dryers in the wood products industry to achieve compliance with regulations.

The wood products industry includes manufacturers of wood-based fiber and particle panel materials. The production processes usually include drying of the wood raw materials to control moisture content. Particle dryers used for this purpose have been identified as significant potential sources of atmospheric pollutant materials. The nature of the emissions in terms of type, quantity, and effect on the environment is variable. Similarly, the factors that influence emissions are complex and variable.

PURPOSE

The major objectives of this project are to define the state of the art in applied control technology for particle dryers in the wood-based fiber and particle panel manufacturing industry and to define the status of compliance on a nationwide basis for particle and fiber dryer installations.

SCOPE

Information for this study has been obtained from many sources. Field investigations were made of 76 particle and fiber dryer installations at 19 manufacturing plants in the states of Oregon, North Carolina, South Carolina, Virginia, and Georgia. These plants represent a cross section of the production of these products in the United States. In the course of the investigation, information was obtained from plant managers, production foremen, plant operators, equipment vendors, and regulatory agencies on the Federal, state, and local levels. An intensive literature search was carried out, and valuable insight was gained from discussions with consultants who have worked in this aspect of emission measurement and control technology.

To ascertain the compliance status and compliance schedules of the industry, data reports of the Compliance Data System (CDS) and National Emission Data System (NEDS) were reviewed. Directories of the Forest Products Industry, the National Particleboard Association, and Acoustical and Board Products Association were utilized to verify identities, locations, and production levels of the various board producers. All EPA regional offices were contacted for supportive information, and some local agencies were contacted.

The report is organized so as to present briefly the basic operations of wood and fiber panel production (Section 3) and the specific functions of the several major dryer configurations (Section 4).

Pollutant emissions from dryer systems are characterized in Section 5, with a brief discussion of emission measurement techniques. Regulations pertaining to particle dryer emissions are summarized in Section 6.

The balance of the report deals with control technology currently applied in the industry, describing (in Section 7) for each major control option the degree of success achieved in meeting regulations, any major problems, approximate costs, and recommended applications. Section 8 summarizes the current known compliance status of dryer units, industry-wide.

For readers unfamiliar with the wood-based fiber and particle panel manufacturing industries, substantial supportive information is presented in the appendices. Appendix A provides introductory notes on the theory of particle drying, and Appendix B identifies the terminology of the industry, including definitions, classifications of particleboards, raw materials used, and finished products of the industry.

2. SUMMARY: STATUS OF CONTROL TECHNOLOGY FOR PARTICLE AND FIBER DRYERS

A major purpose of this study was to summarize the state of the art of technology for control of emissions from particle and fiber dryers. In the course of the effort, 76 dryers were evaluated during visits to 19 manufacturing facilities in Oregon, North Carolina, South Carolina, Virginia, and Georgia. Evaluation of each dryer included assessment of important parameters regarding temperatures, flow rates, species and moisture content of process feed, dryer design, fuel sources, type of control (if any) applied, and degree of success in meeting regulations. The following comments and conclusions are based on discussions with regulatory officials, plant managers, plant operators, and equipment suppliers, and on review of the literature regarding particle dryer emissions and emission control technology.

1. Emissions from particle dryers can be categorized in terms of three typical classes of particles: (1) large particles, principally fibers larger than 10 microns; (2) small, solid particles (the inorganic, noncombustible materials that come primarily from direct combustion of energy sources connected to the dryers); (3) small volatile organic particles, which are the condensation products of volatile materials evaporated from the dryer furnish.*

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* 'Furnish' denotes the material furnished to the process, i.e., the process feed or input.

2. Selection of a system for control of dryer emissions will be based on numerous considerations, including the following:

- What regulations are to be met (grain loading, opacity, mass emission rate, or other)?
- What classes of particles must be controlled in order to meet the requirements?
- What are the capital and operating costs of alternative collection or control devices?
- What are the space requirements?
- What are the energy requirements?
- What are the potential maintenance and operational problems?
- What are the safety considerations (e.g., fire hazard, explosion potential)?
- Will the systems considered operate under fluctuating flow rates?
- If sanderdust is to be used as a fuel for direct combustion, what is its inorganic ash content? Is the sanderdust treated to make it noncombustible? Is the supply sufficient for use on a year-around basis?

Items (1) and (2) concern broad or general considerations. Following are more specific comments:

3. Control of emissions of large-fiber particles is technologically proven and is not particularly difficult. Control can be accomplished with well-designed and operated cyclone systems provided that the furnish is of reasonable mean particle size. For furnish with very small mean particle size, control can be accomplished with wet scrubbers, full-recirculation systems, partial-recirculation systems, secondary medium-energy cyclones, multiple cyclones, or

fabric filters. Cost of installation of these systems ranges from $3/cfm to $7/cfm.

4. Control of inorganic, noncombustible ash can be accomplished with medium-energy scrubbers and probably with fabric filters, although use of the latter has not been demonstrated relative to particle dryers. Because the particles are both small and noncombustible, devices such as low-energy wet scrubbers, recirculation systems, secondary medium-energy cyclones, or multiple cyclones are not appropriate for control of these emissions. A change of the fuel to reduce the ash content would be a reasonable alternative if replacement fuels are available and are not prohibitively expensive.

5. Controlling emissions of inorganic ash content to meet grain loading or mass emission requirements will not necessarily meet opacity requirements. The small particles are particularly visible in a characteristic blue haze.

6. Control of organic volatile components of the wood furnish is possible by two alternative methods. The most widely used and most successful method is to limit the dryer inlet temperatures to levels at which organic materials are not evaporated from the furnish. If this approach is not feasible in light of plant production requirements, then only one of the control methods investigated appears to be acceptable: full recirculation of exhaust gases from the primary cyclone to the combustion chamber on the dryer energy source. Because of the concern over emissions of volatile organics, some elaboration is in order.

Wet scrubbers have been used to control opacity related to volatile organic emissions, but without success. In some cases and under some atmospheric conditions scrubber plumes will mask the blue haze for a long enough period that the system may be judged to be in compliance; under other conditions, however, opacity will exceed the restrictions. Even high-energy scrubbers have not proved successful in controlling submicron particles such as those that cause the classic blue-haze problem.

Partial recirculation systems do not circulate all of the combustible haze-forming particles back to the combustion chamber. The nonrecirculated portion of the exhaust gases creates the opacity, and the systems are ineffective. Medium-energy secondary cyclone systems and multiple cyclones cannot collect submicron size particles and thus are also ineffective.

A single baghouse installed to reduce dryer emissions emits a noticable blue haze from its base. Dilution air that circulates under the fabric filter helps to disperse the condensation particles. Collection of the organic materials in the filter may plug the filter and make it inoperative. This should be recognized as a limitation of filter systems. For control of large fibers and of inorganic emissions, a well-designed and operated fabric filter may be feasible.

It appears that only full-recirculation systems can control opacity caused by volatile organic materials in the submicron size range. As long as temperatures in the combustion zone are maintained at levels high enough to burn the combustible organic materials, opacity due to these materials will be controlled. But an energy penalty is incurred. Full-recirculation systems require significantly higher energy input per pound of water evaporated than does any alternative system. This requirement results from very high exit temperatures of the exhaust gas stream as it enters the atmosphere. The energy requirement may be met by burning inexpensive sanderdust; the use of fossil fuels would be prohibitively expensive. Sanderdust from the manufacture of particleboard may have high ash content. Although some of the fly ash will be captured on the particles in the dryer, most will be recirculated through the dryer and out the exhaust stack. Because of the predominance of fine particles, these fly ash emissions may result in both high grainloading and high opacity.

Test results show that emissions from full-recirculation systems are between 0.10 and 0.20 gr/sdcf* under some operating conditions.

7. Although there is considerable development of technology for control of volatile organic emissions from veneer dryers, transfer of this experimental technology has not been great. Applicability of this technology will be determined by the classes of particles that leave the dryers. Devices for control of blue haze from veneer dryers will not necessarily be successful in control of blue haze due to inorganic fly ash produced in a particle dryer energy source. Low-temperature operation of particle and fiber dryers (as with veneer dryers) will limit organic emissions.

8. No control system is universally applicable. Application at a specific plant is governed by variations in species, particle size, and moisture content of the furnish and in manufacturing processes.

9. Success in meeting emission regulations depends somewhat on the measurement techniques used to determine

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* When grain loadings are expressed under actual nonstandard conditions, they may be considerably smaller (i.e., order of magnitude).

compliance. The measurement techniques often are selected at the discretion of the control agency. For sources involving high levels of volatile organic materials, the measurement technique is crucial.

10. Most, but not all, particle dryers have been tested to determine emission levels. Dryers generating low levels of visible emissions receive less pressure from the agencies for emission testing. In addition, most plants are either operating in compliance with emission limits or are making changes that will bring them into compliance. The industry has made large capital investments specifically for emission control.

There is no doubt that particle dryers can be operated in compliance with most current regulations, particularly those related to concentration, mass emission rates, and opacity. At some plants the changes required in current production practices and/or the capital requirements for purchase and installation of control devices may create serious problems. Operators of dryers that receive a substantial input of energy from boiler exhaust gases generated by fuels having high ash content may be faced with extreme difficulty in meeting regulations. In the interest of energy conservation, it may be warranted to consider revisions to regulations governing emissions from such dryers unless, of course, the regulations are essential for the attainment and/or maintenance of air quality standards.

3. THE PRODUCTION PROCESS

Processes for manufacturing wood-based fiber and particle panel products are briefly summarized in this section. Raw materials are received at the plant site in a wide range of sizes and moisture contents. Since manufacturing requires uniform size and moisture levels, the initial processes are (1) refining of raw materials to yield the required size of fibers or particles, and (2) drying of the fiber or particles. These processes may be performed in reverse order depending on the products. Production of some particleboard products requires two discreet size ranges for the particle furnish. Coarse particles may be used to form the center or core of the panel, and fine particles may be used to form exterior surfaces, which require a very smooth finish. Thus, the furnish for particleboard is often classified as "surface" and "core" materials.

The amount of drying required depends on two major factors: the production process and the initial moisture content* of the raw material. In manufacture of hardboard as well as some insulation board and fiberboard, the moisture content of the material delivered to the board manufacturing machine may be in excess of 15 percent on a dry basis. For

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* Moisture content (MC) may be discussed on a wet basis or a dry basis. The fiber and particle panel industries use the dry basis. The two bases are related as follows:

$$\text{MC (wet)} = \frac{100 \times \text{MC (dry)}}{100 + \text{MC (dry)}} \qquad \text{MC (dry)} = \frac{100 \times \text{MC (wet)}}{100 - \text{MC (wet)}}$$

Where MC is expressed in percent.

most particleboard operations, the moisture levels must be held between 4 and 6 percent (dry basis). (Appendix B provides definitions of board products and associated terminology.)

The initial moisture level for raw materials, discussed later in greater detail, typically varies from high values of 200 percent to low values of 6 to 8 percent. Raw materials whose initial moisture content exceeds 60 percent may entail two stages of drying, particularly when moisture levels in the different components of the furnish vary over a wide range.

Particles including wood chips, planer shavings, sawdust, and flakes are normally dried on a continuous basis in rotary drum dryers. Wood fiber, being much lower in bulk density, is normally dried in a tube dryer with significantly higher volumes of air and lower inlet temperatures. Appendix A presents a discussion of particle drying theory.

After the raw materials are dried and particle size distributions are controlled within acceptable limits, resins are added in a blending machine. The prepared furnish is then carried to the mat former, where it is built up into a uniformly thick layer of uncompressed, loose particles. The mats may be formed on individual backing sheets (cauls) or they may be formed on a continuously moving screen wire bed. The loose mat is usually subjected to moderate compaction and is then placed in a steam-heated press. The high temperature and pressure in the press sets up the bonding resins to give the required strength characteristics. The smooth surfaces of the press leave the panels with correspondingly smooth surfaces.

When the press cycle is completed, the panels are removed and allowed to cool. Preset saws trim the edges and ends to meet size requirements. If the surface requires sanding, the individual panels are routed to automatic high-speed surface sanders. Packaging and shipping operations complete the basic manufacturing process. Figure 3-1 depicts process flow in a typical particleboard plant.

Approximately 75 plants are manufacturing particleboard in the U.S., with annual production exceeding 5 billion square feet, on the basis of 3/4-inch-thick product. Twenty hardboard plants produce 3.5 billion square feet of products on a 1/8-inch-thick basis.

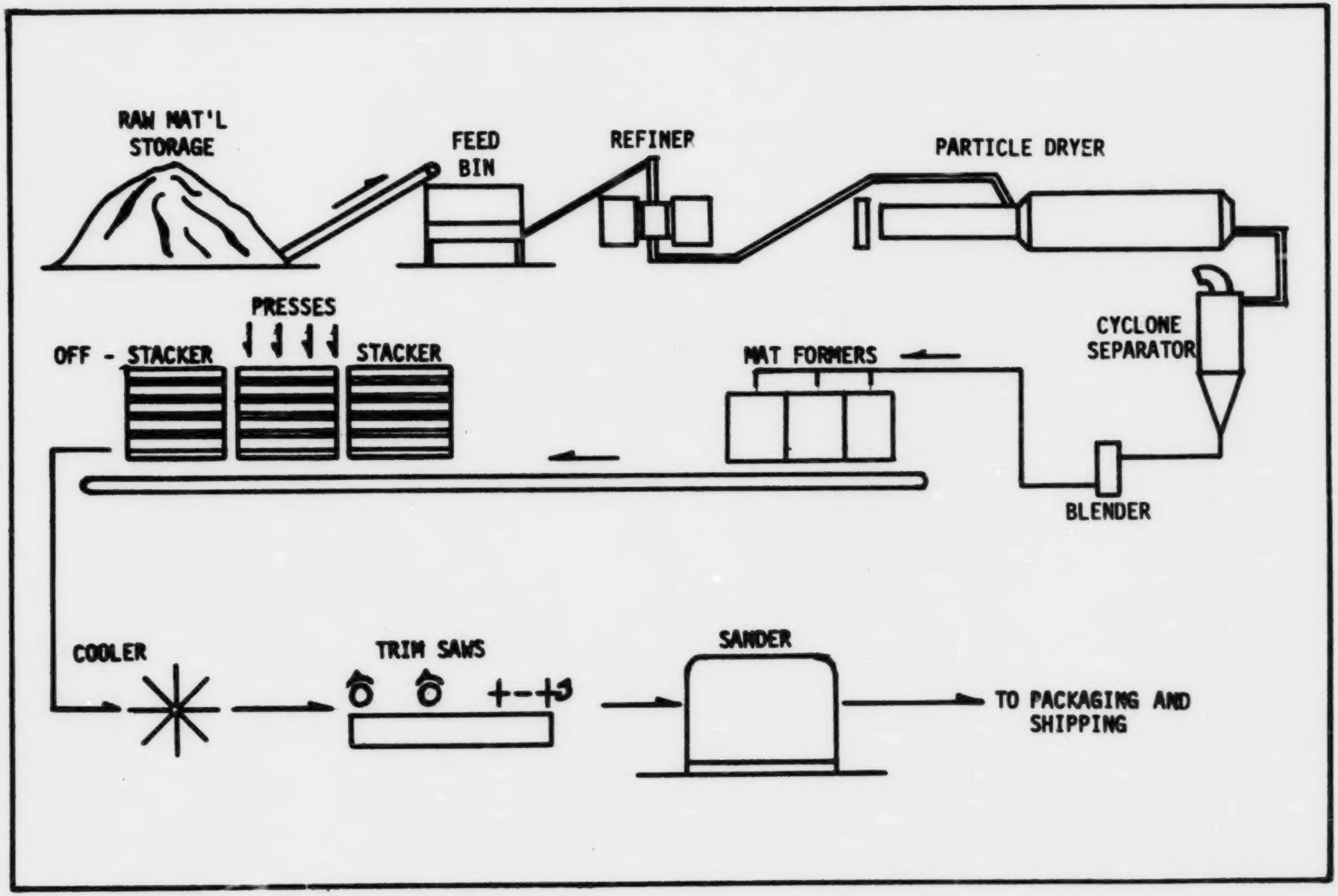
RAW MAT'L STORAGE
FEED BIN
REFINER
PARTICLE DRYER
PRESSES
OFF - STACKER
STACKER
MAT FORMERS
CYCLONE SEPARATOR
BLENDER
COOLER
TRIM SAWS
SANDER
TO PACKAGING AND SHIPPING

Figure 3-1. Flow diagram of a typical particleboard plant.

4. PARTICLE AND FIBER DRYING SYSTEMS

Particle and fiber dryers are integrated into complex production systems. At most plants the dryer systems consist of five principle components: (1) a heat-energy input system, (2) a particle or fiber feed system, (3) the dryer, in which particles (fibers) are subjected to sufficient residence time and turbulence at elevated temperatures to separate moisture from the particles, (4) a system to separate the dried particles (fibers) from their carrier gas stream, and (5) a fan system for moving the particles and gas stream through the dryer. Certain dryer systems include components whose purpose is to provide turbulence, mechanical mixing, separation of particles (fibers), or other functions to aid in separating moisture from the wood feed stock.

ENERGY INPUT SYSTEMS

In most dryer systems, the particles are carried through the various components by a carrier gas stream (air). The air must be heated from its incoming temperature level (ambient in most cases) to a level high enough to evaporate the moisture from the wood. Energy required to heat the air is provided by a variety of sources. The preheat temperature of the air stream is generally controlled by the temperature of the gas stream leaving the dryer, since this has proved to be the most efficient means of controlling the discharge moisture content of the wood particles (fibers).

Temperature of the incoming air may be raised by direct or indirect contact heat exchangers. Indirect contact exchangers are used only when steam or hot water serves as the energy source (see Figure 4-1). For all other energy sources, one or more fuels are burned and the resulting high-temperature combustion products are mixed directly with the incoming air stream. As a precaution against potential fire or explosion, design of combustion-based energy systems must ensure that all of the fuel is completely oxidized before it comes in contact with the feed stock of particles or fibers. Typical combustion systems include a long, cylindrical, stationary chamber to ensure complete combustion and thorough mixing of the incoming air stream before it contacts the feed stock (see Figure 4-2).

Several plants have combined the use of steam-heated systems and direct combustion systems to provide energy input to the dryer(s). This procedure is based on the availability of steam capacity at the plant and the relative cost and availability of alternate energy sources for direct combustion.

PARTICLE/FIBER FEED SYSTEMS

The rate of flow of moist wood particles or fibers to the drying system must be regulated to bring about uniform drying and control of the exit moisture content. The rate of feed is based on production needs and is limited by the operating parameters of the dryer system. Another approach would be to monitor and control the rate of water input to the dryer (i.e., the water contained in the particles). This would ensure more uniform evaporation rates in the dryer and therefore more uniform exit moisture levels of the wood particles or fibers. However, continuous monitoring of

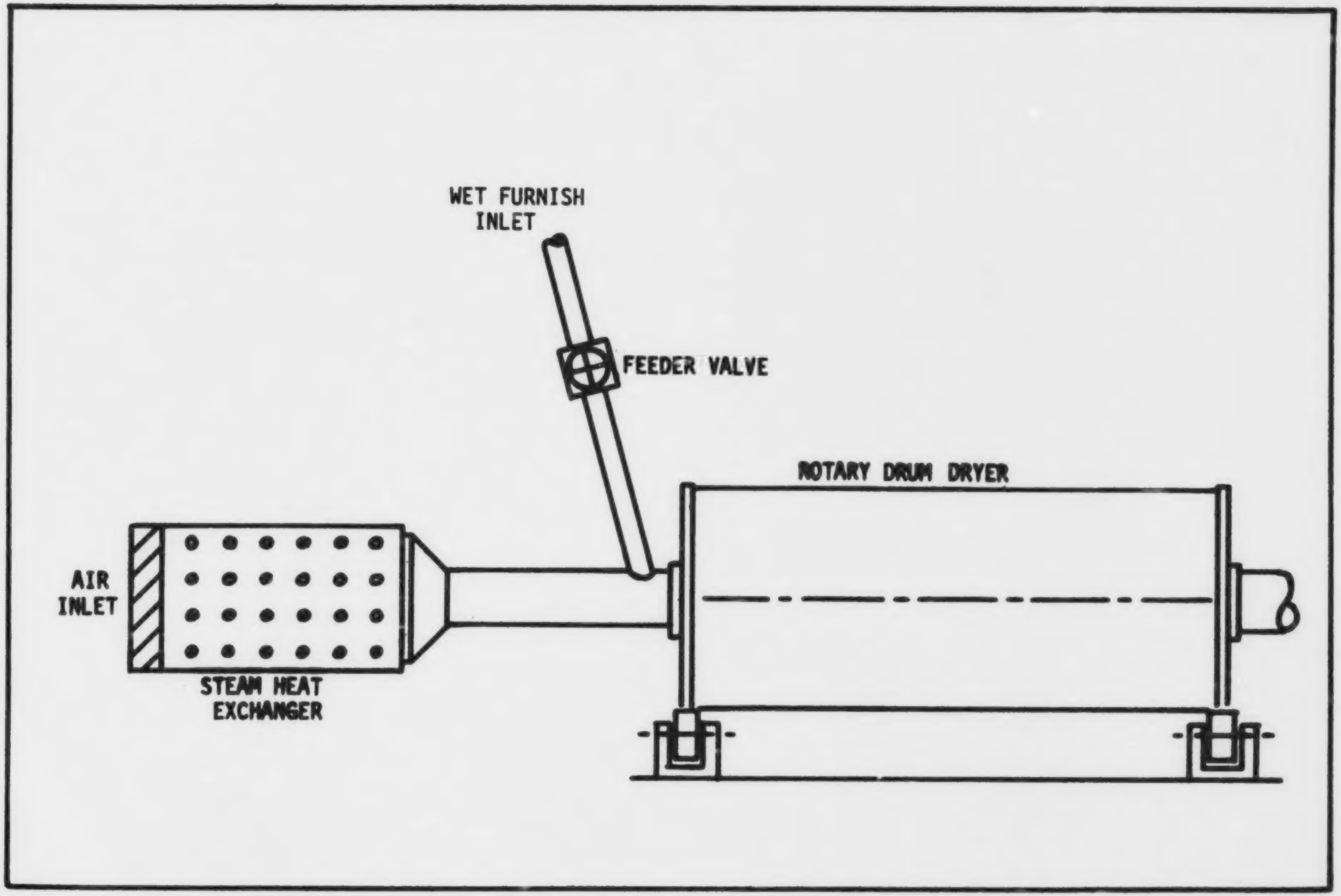
WET FURNISH
INLET
FEEDER VALVE
ROTARY DRUM DRYER
AIR
INLET
STEAM HEAT
EXCHANGER

Figure 4-1. Steam heat exchanger used to heat air stream for drying particleboard feedstock.

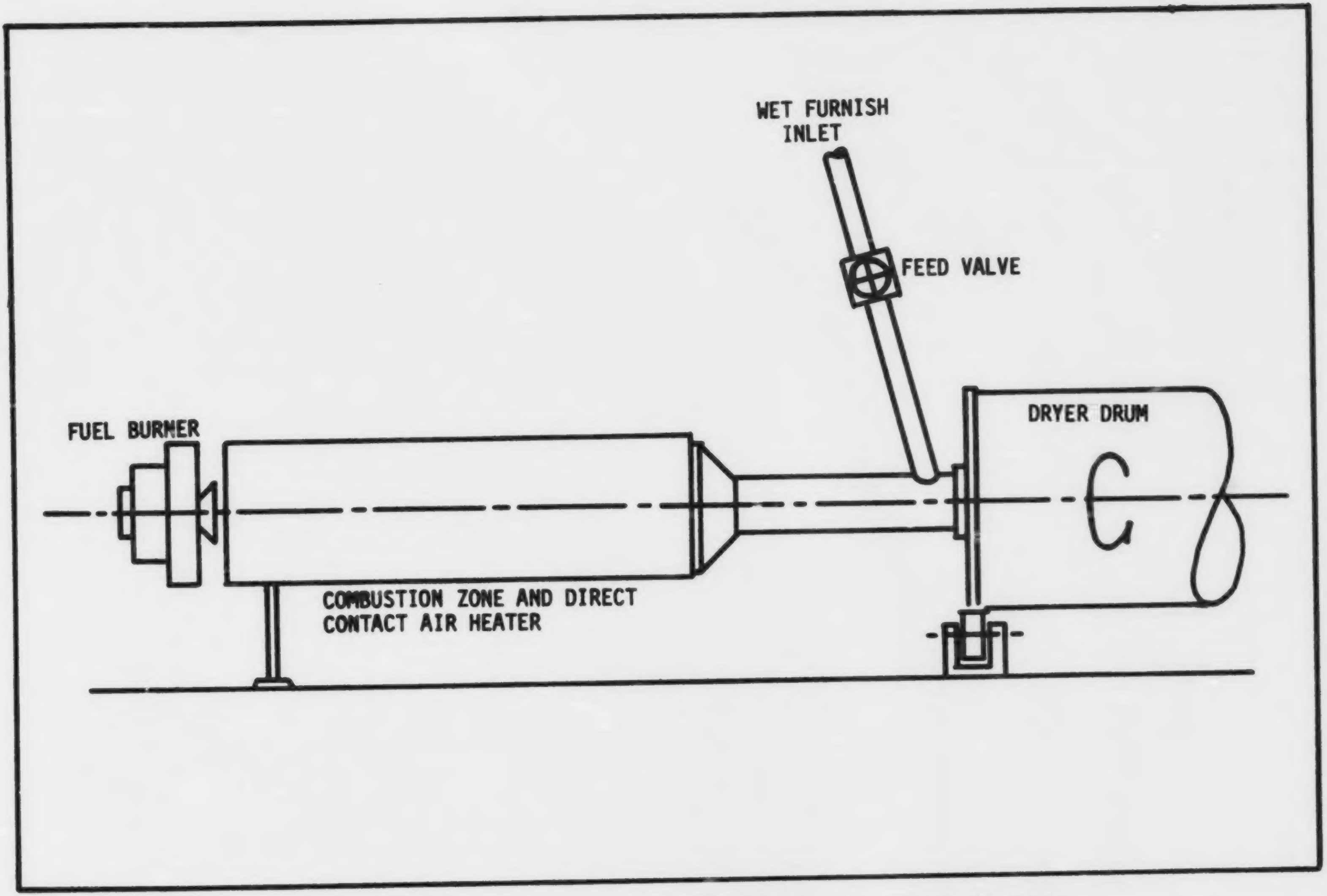
WET FURNISH
INLET
FEED VALVE
FUEL BURNER
DRYER DRUM
COMBUSTION ZONE AND DIRECT
CONTACT AIR HEATER

Figure 4-2. Direct-combustion energy system used to heat ambient air stream for a particle dryer.

the input moisture to the dryer is difficult to accomplish. Furthermore, because of variations in size and morphology of the particles, the rate of drying is highly variable. Control of feed rate therefore seems adequate for production purposes.

A typical feed system is illustrated in Figure 4-3. A material transfer mechanism, usually a pneumatic system culminating in a cyclone separator, carries the moist feed stock to a storage hopper. From the hopper the stock is dropped into a rotary (star) feed valve. The rpm of the rotary feed valve controls the rate of flow of the wood feed stock to the dryer. Flow rate is directly influenced by the bulk density of the feed stock, and any abrupt changes in bulk density will alter the exit moisture level. For most systems, this is not a severe limitation. The rpm of the rotary valve is generally controlled by a DC drive or a variable-speed reducer coupled to an AC drive.

DRYER DESIGNS

Particle dryers are manufactured in a variety of configurations, sizes, and material handling capacities to meet specific production requirements. The basic purpose of the dryer is to subject wood particles or fibers for a sufficient time period to physical conditions conducive to evaporation of water from the wood. The dryer therefore must be large enough to allow sufficient residence time and must provide for movement of particles to increase the rate of evaporation. Tumbling action, jets of high-temperature air, rakes or paddles, and other methods are used to bring about movement of particles relative to each other and to the drying air stream. Beyond these basic requirements,

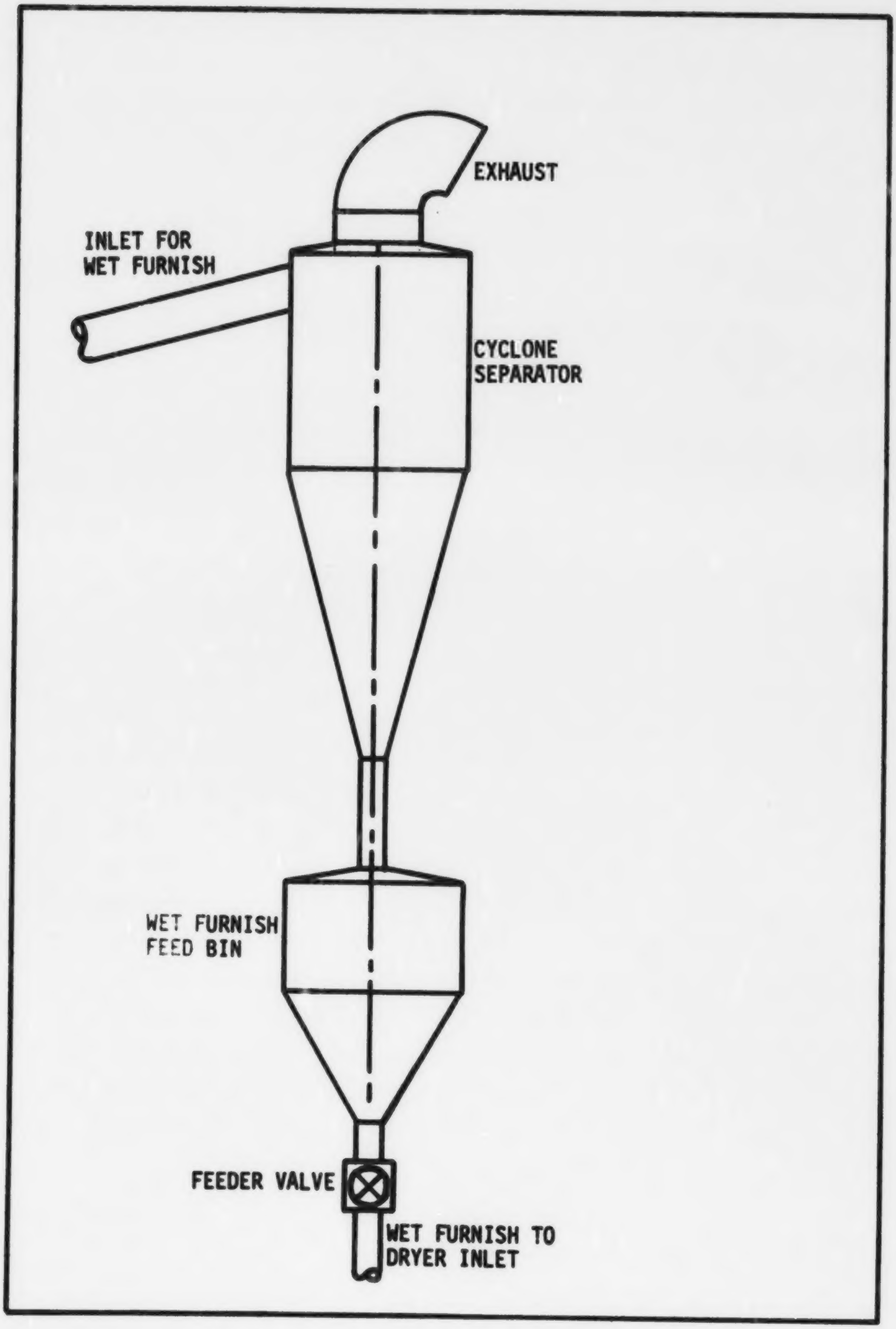
EXHAUST
INLET FOR WET FURNISH
CYCLONE SEPARATOR
WET FURNISH FEED BIN
FEEDER VALVE
WET FURNISH TO DRYER INLET

Figure 4-3. Typical particle feed system.

dryer design entails considerations of energy requirements, reliability, maintenance, and capital costs.

The two principal design categories are tube dryers and drum dryers. Drum dryers may incorporate fixed or rotary drums, and rotary drum dryers may entail one or three passes. These basic designs are briefly described in the following paragraphs.

Tube Dryers

Tube dryers, which are used principally to dry fibers rather than particles or small chips of wood feed stock, are nothing more than long tubes through which the heated air stream and the fibers pass. As illustrated in Figure 4-4, the tube is designed to accommodate the carrier gas stream at the minimum velocities required to keep the fibers entrained long enough that the moisture can evaporate to the required level. The dryer includes no moving parts and therefore is inexpensive to construct and maintain (relative to the more complex rotary drum dryers). The tube dryer, however, requires more energy to evaporate a pound of water than does the drum dryer because larger volumes of heated air are reuqired to carry the fibers through the tube dryer.

An interesting modification of the tube dryer is the 'flash' dryer (Figure 4-5). Whereas in the tube dryer all of the particles move through the tube at approximately the same rate, in a flash dryer the moist particles are injected at the bottom and are suspended in an upward-flowing gas stream. As the particles become dryer, their density decreases and they are carried upward and into the collector system. The heavier, still-moist particles remain in suspension until enough moisture is evaporated to allow the carrier gas stream to remove them from the dryer. Thus, the flash dryer involves considerable relative motion between

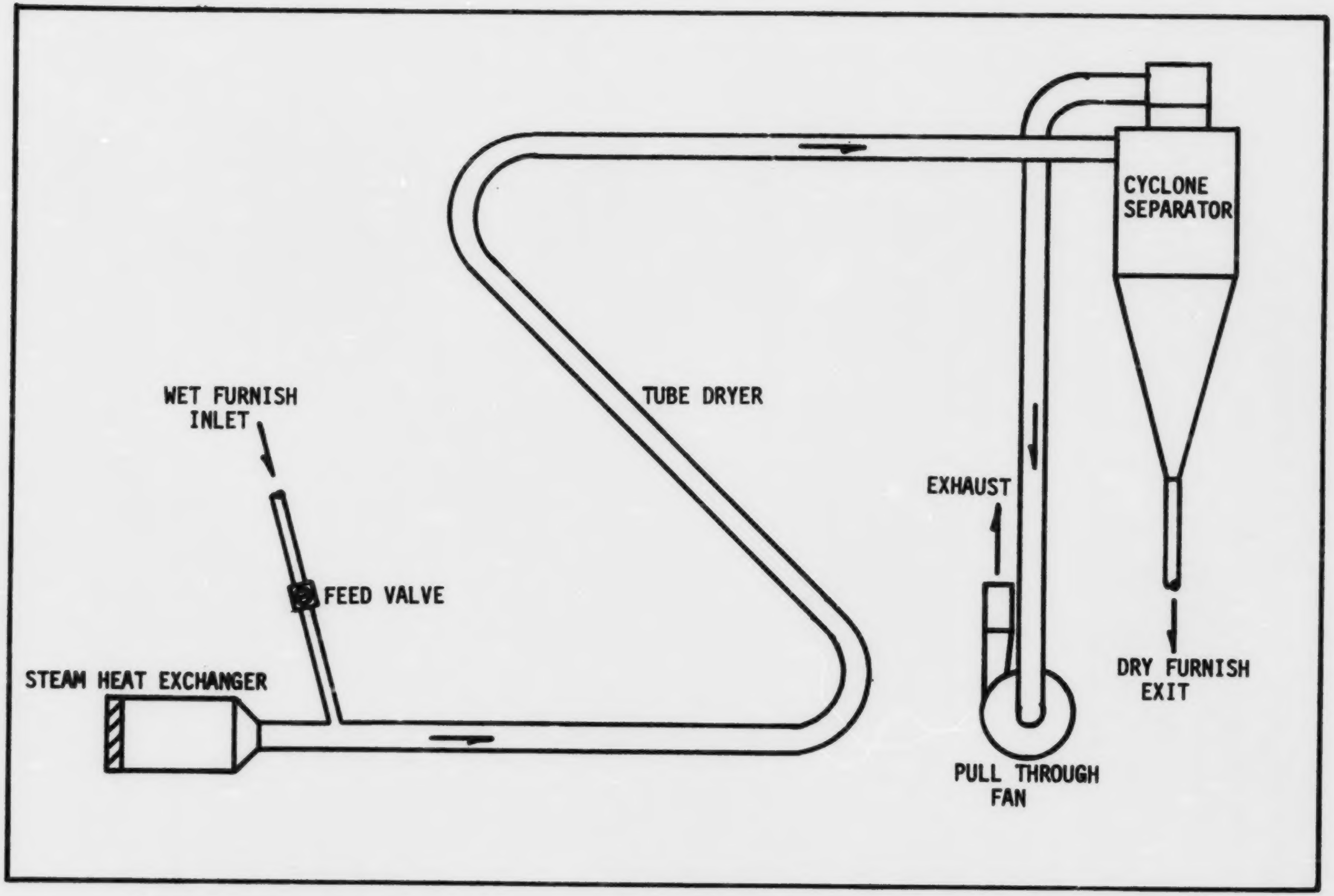
WET FURNISH INLET
TUBE DRYER
CYCLONE SEPARATOR
EXHAUST
FEED VALVE
STEAM HEAT EXCHANGER
DRY FURNISH EXIT
PULL THROUGH FAN

Figure 4-4. Schematic diagram of a typical tube-type fiber dryer.

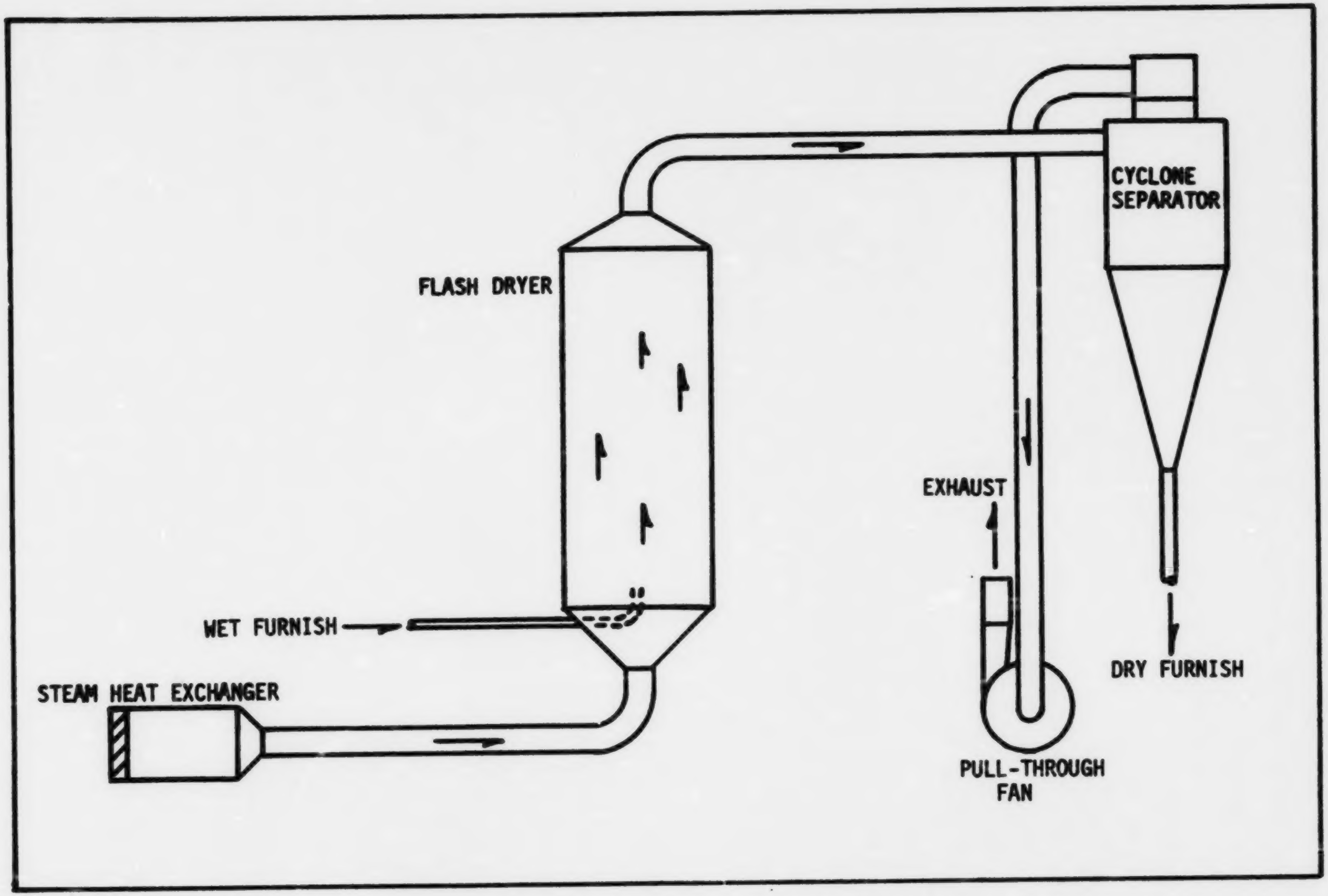
CYCLONE SEPARATOR
FLASH DRYER
EXHAUST
DRY FURNISH
WET FURNISH
STEAM HEAT EXCHANGER
PULL-THROUGH FAN

Figure 4-5. Typical flash dryer for particle and fiber drying.

the particles and the carrier gas stream. Flash dryers, like tube dryers, are stationary units with no moving parts.

Drum Dryers

Drum dryers are the most commonly used in the wood products industry. They were developed for drying agricultural crops and are still used more extensively for crop drying than for drying wood products. Drum dryers are designed with stationary or rotating drums. Use of stationary drums requires some device or system to keep the moist particles moving through the dryer and to maintain turbulent motion of the particles with respect to the air stream. Both of these requirements can be met with systems of moving rakers inside the drum or with high-velocity air jets. Manufacturers of stationary drum dryers advertise competitive capital costs, since the drums do not rotate and therefore do not require moving parts such as shafts, bearings, and the like. Each of the stationary drum dryers evaluated in this project was a single-pass design; that is, moist particles enter the drum in one end and leave the drum at the opposite end after a single pass through the system. A single-pass, stationary dryer drum is illustrated in Figure 4-6.

Rotary drum dryers are large cylinders with horizontal axes, having either single-pass or triple-pass design, as illustrated in Figures 4-7 and 4-8. In either case, the drums are externally supported on trunion mounts; as they rotate about their axes, the rotary motion and the air stream moving through the dryer transport the wood feed from the inlet to the outlet. Residence time is controlled by the size of the drum, the rate of revolution, and the rate of gas flow through the drum.

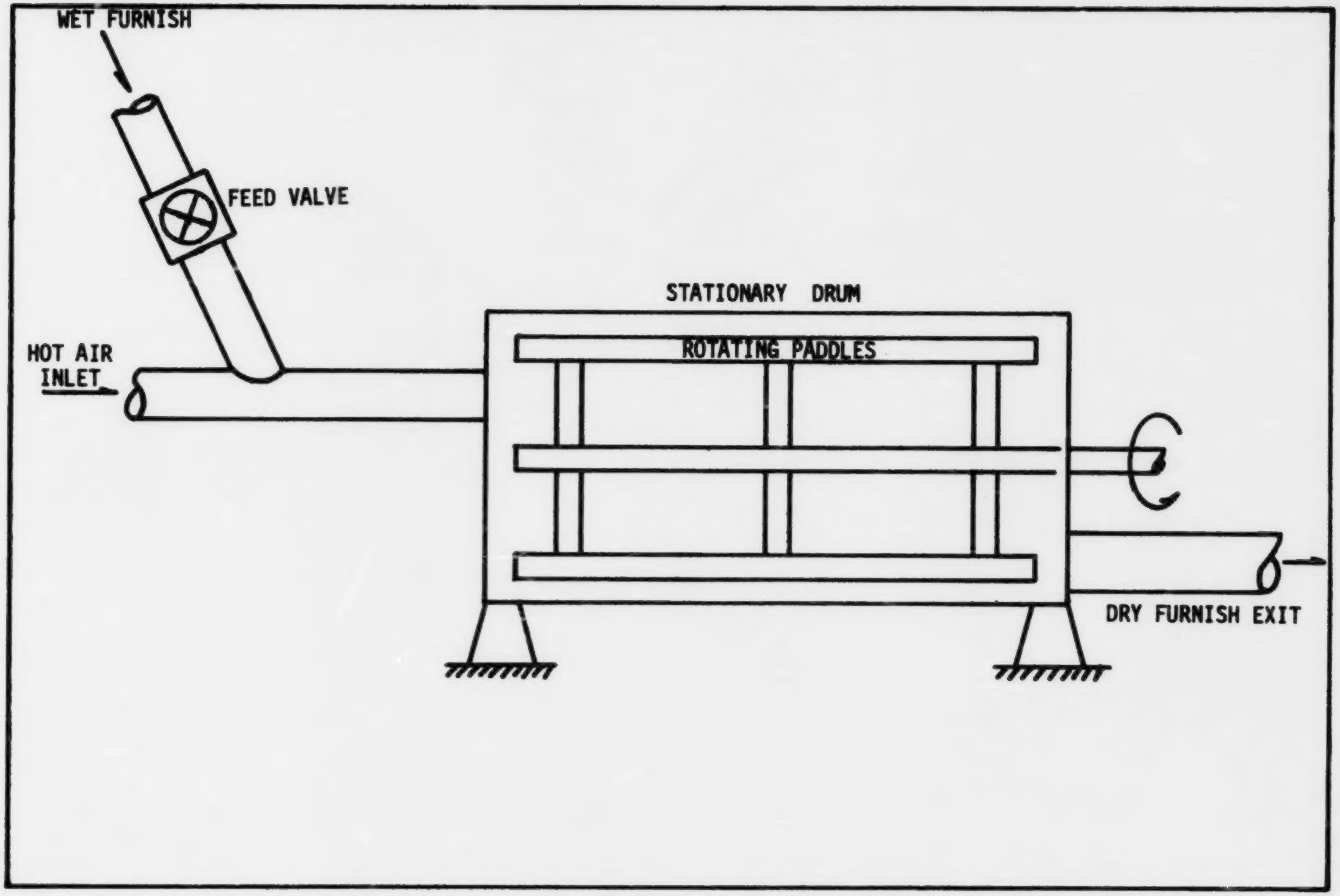
WET FURNISH
FEED VALVE
HOT AIR INLET
STATIONARY DRUM
ROTATING PADDLES
DRY FURNISH EXIT

Figure 4-6. Schematic diagram of a typical single-pass stationary drum dryer.

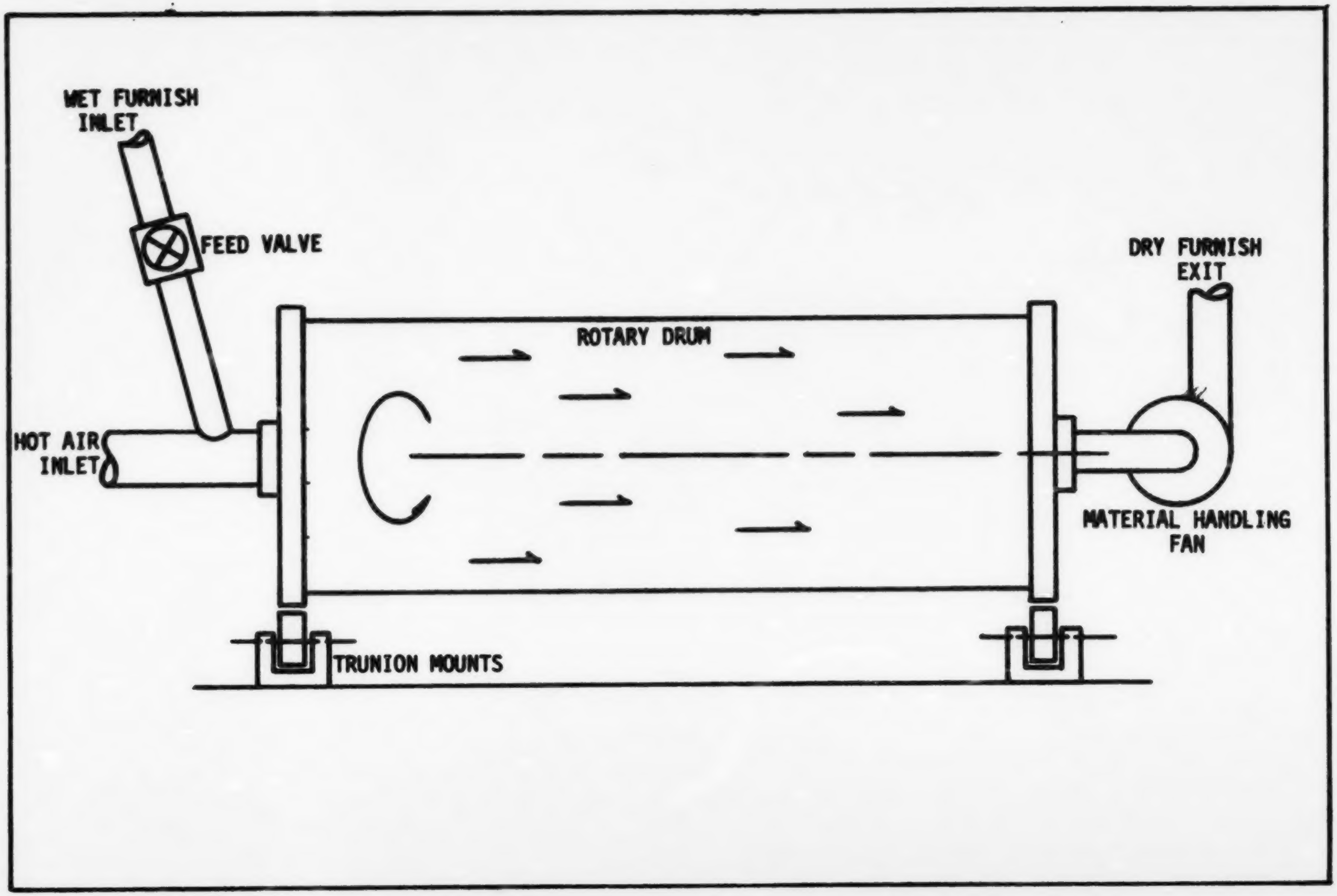
WET FURNISH
INLET
FEED VALVE
HOT AIR
INLET
ROTARY DRUM
DRY FURNISH
EXIT
MATERIAL HANDLING
FAN
TRUNION MOUNTS

Figure 4-7. Schematic diagram of a single-pass rotary drum dryer.

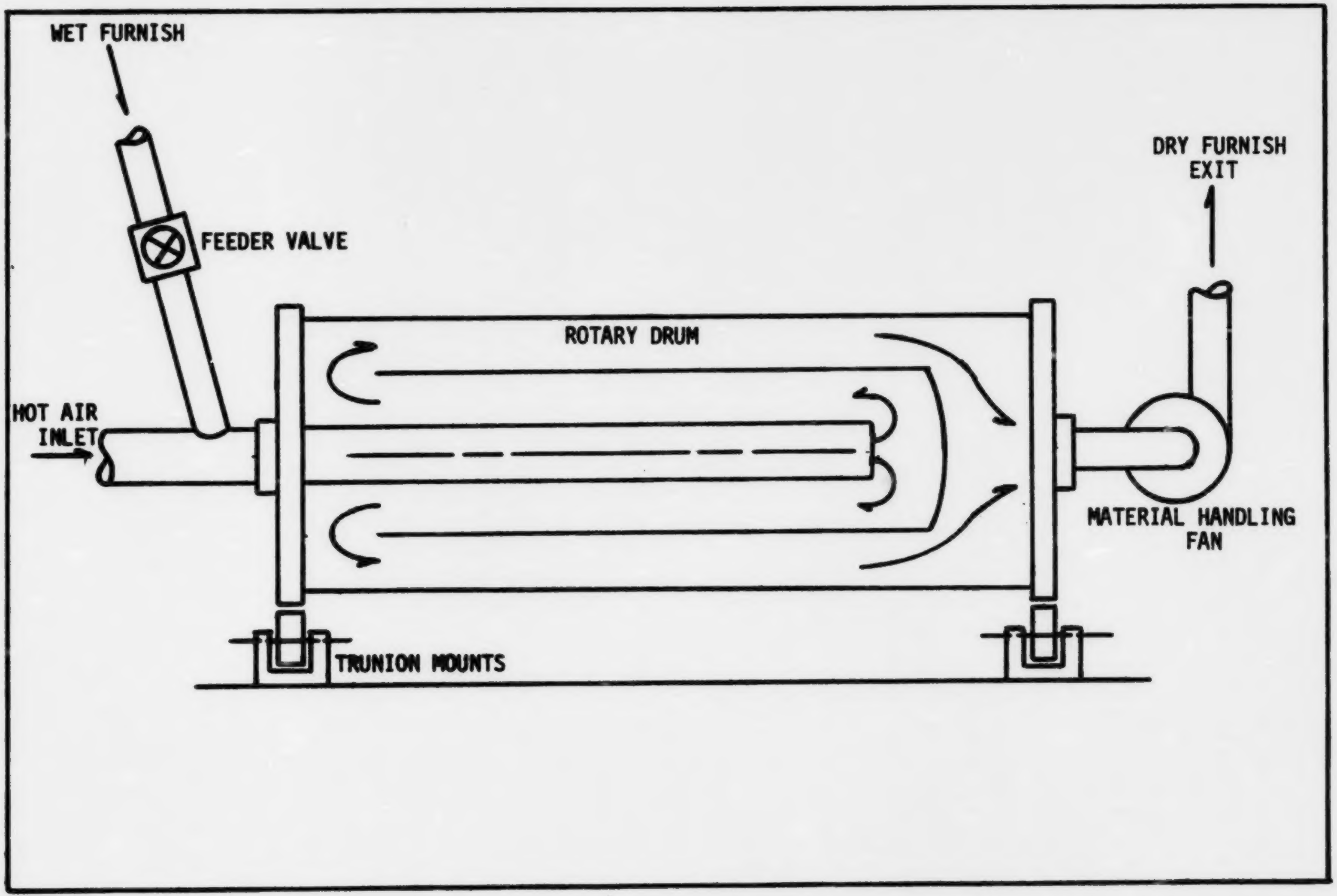
WET FURNISH
FEEDER VALVE
HOT AIR INLET
ROTARY DRUM
DRY FURNISH EXIT
MATERIAL HANDLING FAN
TRUNION MOUNTS

Figure 4-8. Schematic diagram of a triple-pass rotary drum dryer.

The single-pass design is less efficient in terms of space utilization than the triple-pass design. Although this can be compensated for by installing "fill" in single-pass drums, only two mills have used this procedure. The triple-pass drum is by far the most common in wood products industries. A typical triple-pass drum measures 90 inches in diameter by 28 feet long.

PARTICLE SEPARATION SYSTEMS

After the particles leave the dryers, they are separated from the carrier gas stream, usually in cyclone separators. Most dryers are directly connected to a single cyclone so that the entire gas stream from the dryer enters the cyclone (see Figures 4-4 and 4-5). Centrifugal force exerted on the particles inside the cyclone separates them from the gas stream. The particles are carried to the bottom of the cyclone and are discharged into a bin or receiving hopper. The carrier gas stream exits from the top of the cyclone.

The phrase "primary cyclone" designates the first cyclone in a system downstream from the particle dryer. Emissions to the atmosphere of potentially pollutant materials from particle dryers occur principally at the gas exit duct of the primary cyclone. At this point the gas stream contains any fibers or wood particles that were not collected in the cyclone. It also contains products of combustion from the energy source for the dryer (unless the dryer is heated by steam or hot water) and may contain volatile organic materials evaporated from the wood particle feed stock.

Because the exit duct of the primary cyclone is the principle point of pollutant emission, design of the primary cyclone is of critical importance in limiting these emissions, particularly of wood fiber materials. The collection efficiency of cyclones is influenced by many factors, including size distribution of the particles to be separated, particle density, moisture content and temperature of the carrier gas stream, gas flow rate, and geometry of the cyclone. Many technical papers regarding cyclone design[9] could be consulted in the event that emission problems are traced to inefficient cyclone design.

FAN SYSTEMS

The principle means of moving particles through dryers, associated duct work, and cyclones is by partial or total suspension in a gas stream moving through the system. Large industrial centrifugal fans used to move the gas through the system may be placed between the dryer and the primary cyclone or downstream from the primary cyclone. In the latter case, the cyclone is said to be a 'pull-through' system whereas when the fan precedes the cyclone the gas stream is 'pushed' into the cyclone. In terms of overall system efficiency, location of the fan makes no great difference. If the fan is placed downstream from the cyclone, however, a rotary (star) discharge valve must be incorporated on the material exit from the cyclone.

Power requirements for fan systems vary over a wide range, dependent on the size, flow rates, and differential pressure requirements of the system. Systems equipped with pollution control devices may require much more fan power than systems without such devices. Typical fan power requirements for uncontrolled systems range from 50 to 150 horsepower.

For most dryer systems, the fans are constant-speed units connected directly to 440-volt, 3-phase drives. Since gas flow through a given dryer is held constant in most operations, no dampers are used to vary the gas flow rates.

Following this discussion of the basic components of particle dryer systems, attention is now given to common modifications of dryer designs and to the principle energy sources for dryer operation.

DRYERS CONNECTED IN SERIES

Moisture content of the furnish for wood panel products must be controlled to close tolerances, usually within 1 percent of the average level required. If the raw materials received at the plant site are of reasonably uniform moisture content, the drying process can be accomplished in a single stage. In practice, however, initial moisture levels do vary over a wide range. Moisture content of sawdust may be more than 200 percent (dry basis); that of green planer shavings, about 100 percent, and of recycled edge and end trim, about 6 percent. If these materials are fed to a common dryer, it would be difficult to dry the sawdust to the 6 percent level without burning the already dry edge and end trim. This problem can be resolved in two ways. First, raw materials with high initial moisture levels can be fed to a 'green' dryer, or predryer, which is the first dryer in a series of two. Moisture levels at the exit from the green dryer may range from 12 to 15 percent (dry basis). Another solution is to mix the raw feed so that the resultant average moisture level is reasonably uniform. Such mixing may be done prior to a green dryer. Final drying is done in a second-stage dryer, to which typical input moisture levels are 12 to 15 percent. Figure 4-9 illustrates a typical two-stage particle dryer system.

DRYERS EQUIPPED WITH PARTIAL-AIR-RECIRCULATION SYSTEMS

Partial recirculation of the exit gases from the primary cyclone to the dryer can reduce the energy requirement per pound of water evaporated.[4] Another advantage is that the gas stream to be recycled is picked up at the perimeter of the primary cyclone exit duct, which is the zone of highest concentration of escaping particles. The particles are thus recycled to the dryer rather than added to the system emissions. A typical system for partial recirculation of air is illustrated in Figure 4-10.

In spite of the obvious energy and environmental benefits of partial-recirculation systems, few have been installed in the industry. Such systems are of course more expensive to install than nonrecycling systems. Further, the strong incentives to reduce particle emissions and to reduce energy requirements are relatively recent.

DRYERS EQUIPPED WITH FULL EXHAUST GAS RECIRCULATION SYSTEMS

The discussion of drying theory in Appendix A indicates possible economic benefits of recirculating up to 60 percent of the exhaust gas stream. An increasing number of dryers, however, are designed to recirculate the entire exhaust gas stream. This is being done, in spite of high energy costs of operation and added capital costs for installation, because of two significant advantages offered by a full-recirculation system.

In the past, particle dryers have been heated with steam or fired with fossil-based fuels, such as natural gas

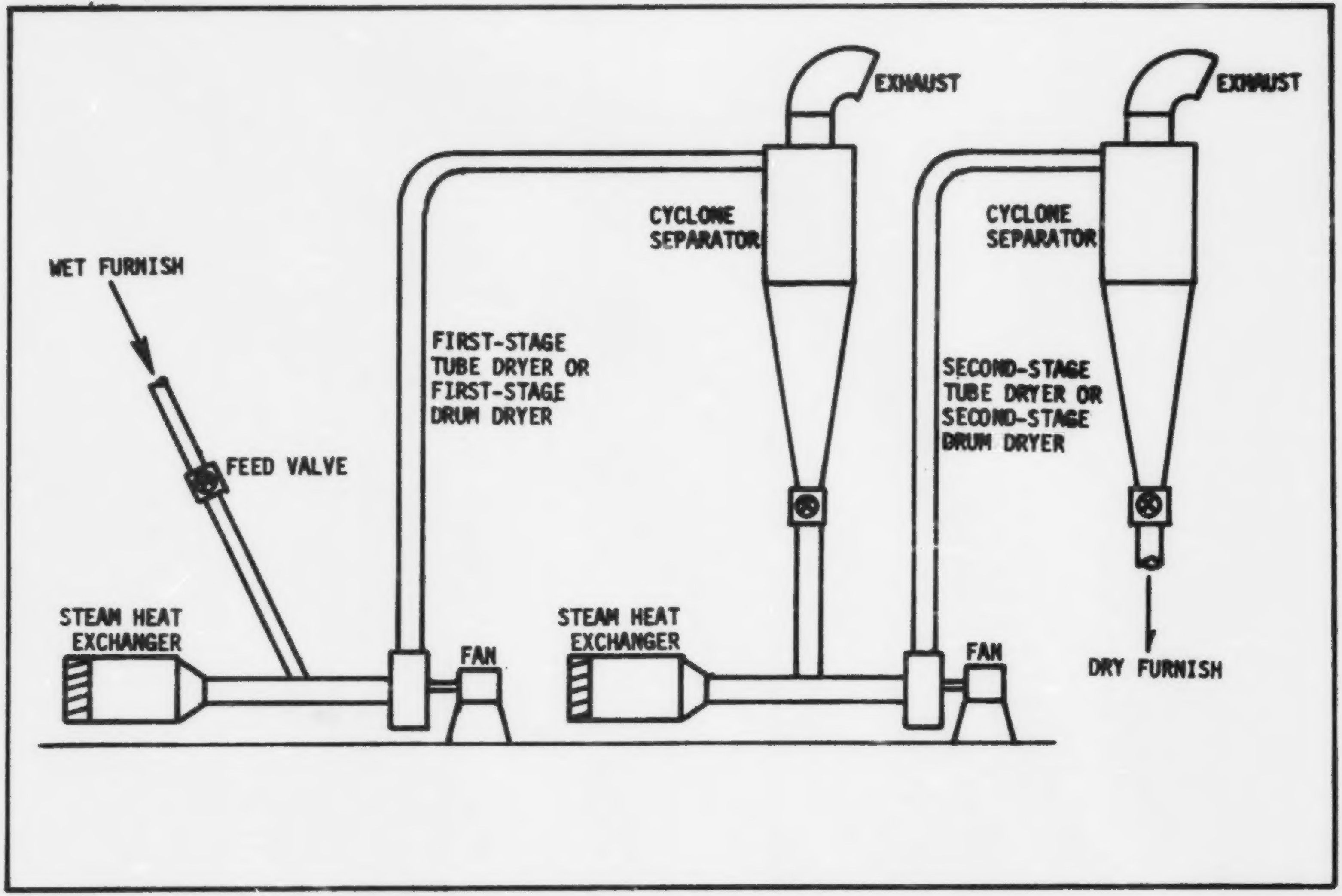
EXHAUST
EXHAUST
CYCLONE SEPARATOR
CYCLONE SEPARATOR
WET FURNISH
FIRST-STAGE TUBE DRYER OR FIRST-STAGE DRUM DRYER
SECOND-STAGE TUBE DRYER OR SECOND-STAGE DRUM DRYER
FEED VALVE
STEAM HEAT EXCHANGER
STEAM HEAT EXCHANGER
FAN
FAN
DRY FURNISH

Figure 4-9. Schematic illustration of a typical two-stage particle dryer system.

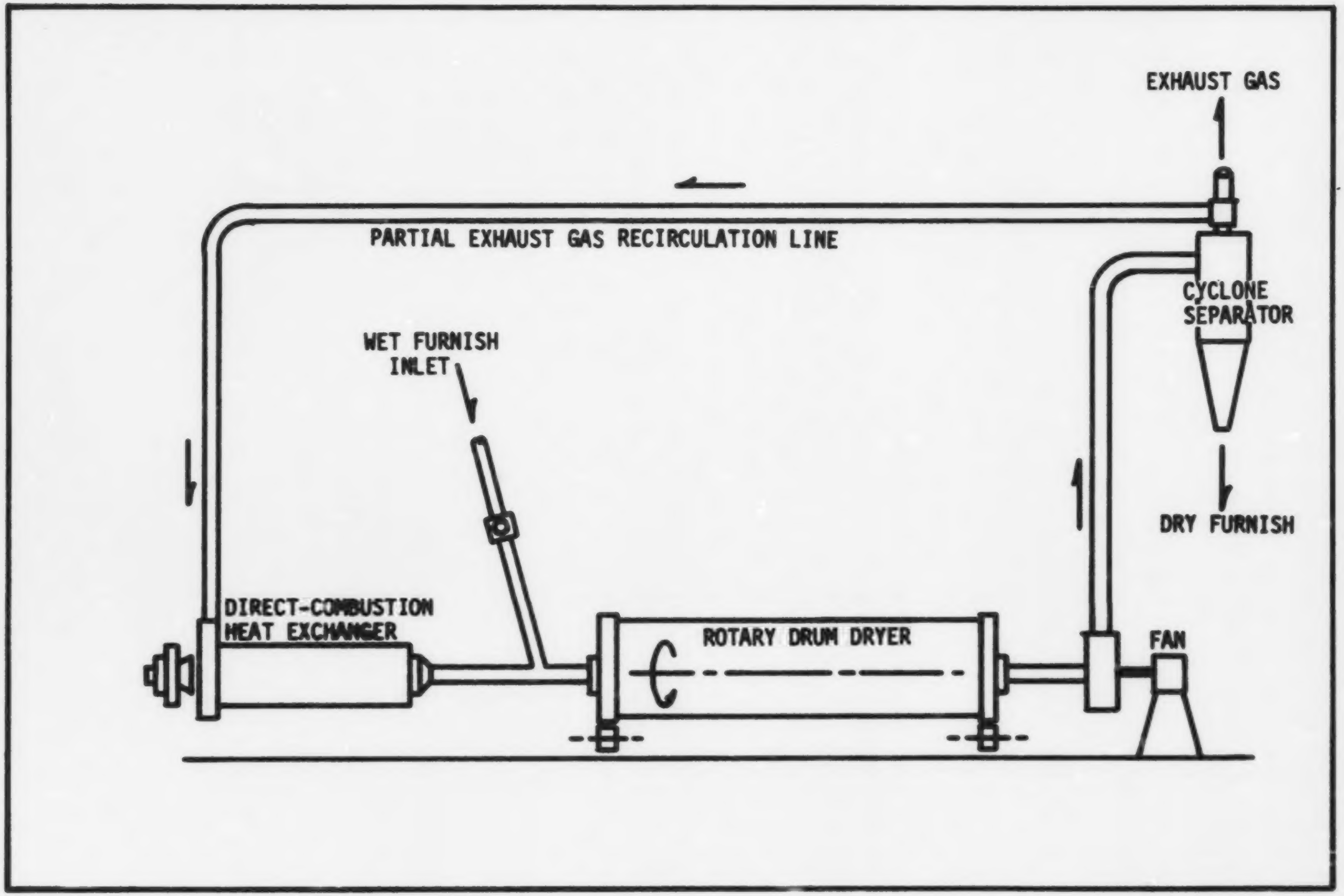
EXHAUST GAS
PARTIAL EXHAUST GAS RECIRCULATION LINE
CYCLONE SEPARATOR
WET FURNISH INLET
DRY FURNISH
DIRECT-COMBUSTION HEAT EXCHANGER
ROTARY DRUM DRYER
FAN

Figure 4-10. Schematic illustration of a typical dryer equipped for partial recirculation of the gas stream.

or propane. More recently, plants having sanding operations that generate substantial quantities of sanderdust have been using this material to replace high-cost fossil fuels. In effect, plants with sufficient sanderdust for fuel can ignore the added energy requirement for full exhaust gas recycling on particle dryers. Several plants have justified the capital cost of conversion to sanderdust firing on the basis of fuel savings alone. There are, however, several constraints on the use of sanderdust as fuel. Not all plants sand their finished panel products. Of those that do, not all generate enough sanderdust on a continuous basis to provide adequate energy for particle drying. Furthermore, not all sanderdust is combustible. If panel products are treated to make them fire resistant or nonflammable, the sanderdust cannot be used as an energy source.

The second and perhaps the most important incentive for use of full-recirculation systems is control of emissions from particle dryers. Some portions of the dryer emissions may be combustible, the percentage varying among dryer systems and depending upon many factors. Where dryer emissions must be reduced to meet regulations and these emissions contain a high percentage of combustible materials, the use of full exhaust gas recycle systems can be a practical means of emission control.

The design of these systems is relatively straightforward. As illustrated in Figure 4-11, the material exiting from the primary cyclone is ducted back to the inlet area of the dryer.[8] In some installations the entire gas volume is carried into the combustion chamber; in others, it is split so that a portion enters the combustion chamber and the remainder is used for dilution air on the inlet to the

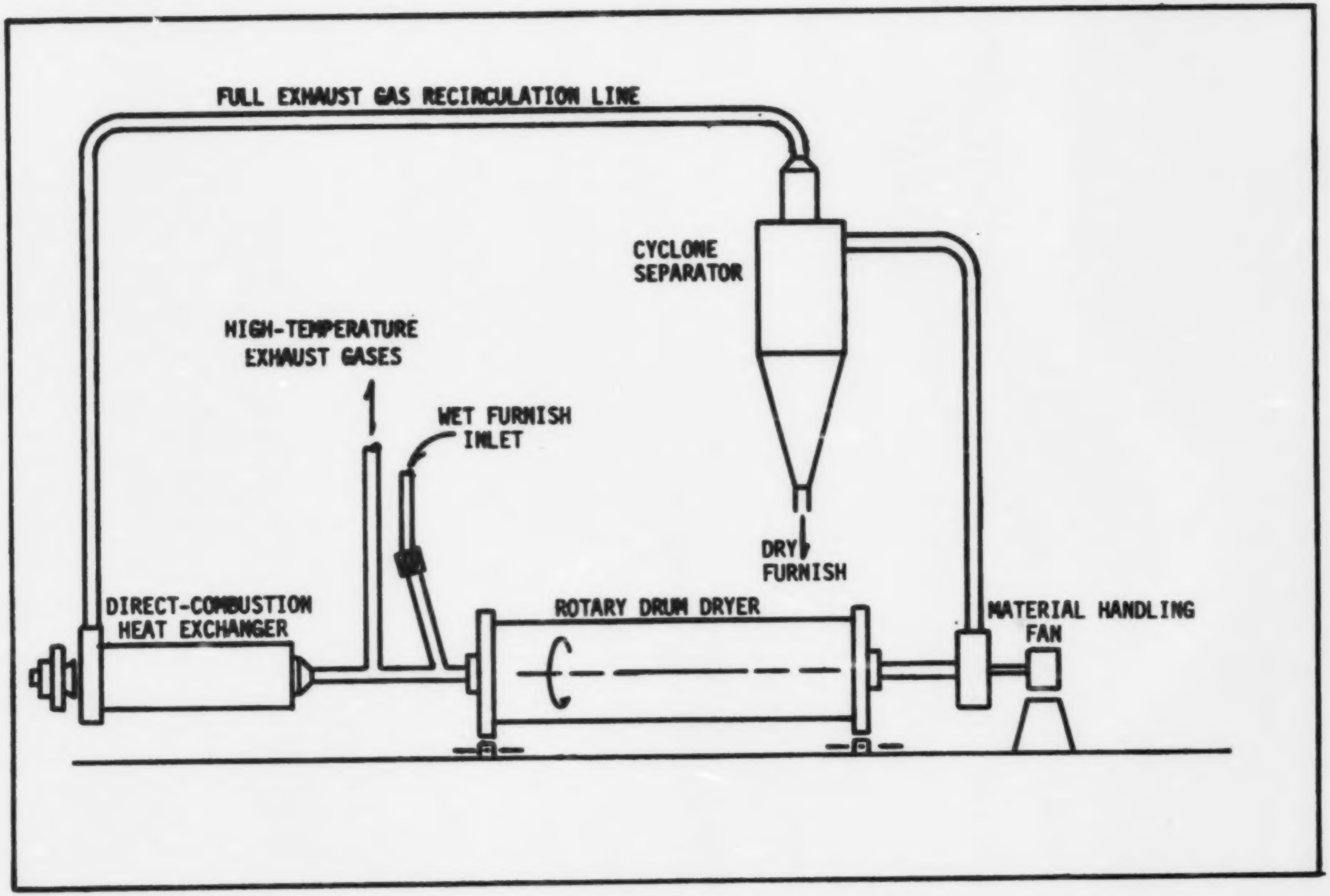
FULL EXHAUST GAS RECIRCULATION LINE
CYCLONE SEPARATOR
HIGH-TEMPERATURE EXHAUST GASES
WET FURNISH INLET
DRY FURNISH
DIRECT-COMBUSTION HEAT EXCHANGER
ROTARY DRUM DRYER
MATERIAL HANDLING FAN

Figure 4-11. Schematic diagram of a particle dryer equipped with full exhaust gas recirculation system.

dryer. The only exit gas stream from the system comes directly from the combustion chamber exhaust. This stream is at high temperature (typically 800 to 1600°F) and contains little, if any, combustible material. As a note of interest, patents issued to the Stearns Rogers Co. for full-recirculation systems are included in Appendix C.

It is important to note again the practical limits on installation of full-recirculation systems. They require significantly higher energy input than do partial-recirculation systems or nonrecirculating systems and therefore are practical only for plants that have access to low-cost fuels such as residual sanderdust. Second, they are practical in controlling emissions of combustible materials only; they are of no value in controlling noncombustible emissions. In addition, they can be used only in conjunction with direct-fired dryers. Dryers equipped exclusively with steam heaters or hot water heaters are not advantageous for use with full-recirculation systems.

ENERGY SOURCES FOR DRYERS

Energy requirements for particle or fiber dryers can be high. For example, consider a dryer with a moderate throughput rate of 30,000 pounds per hour of wet furnish. If the material enters the dryer at 100 percent moisture (dry basis) and leaves at 5 percent moisture, the energy input to the dryer may be in the range of 25 million Btu per hour.

Sources of energy to the dryer may be grouped in four principle categories:

- Indirect heating with steam or hot water circulating systems.
- Direct heating with exhaust gases from nearby boiler installations.

- Direct firing of fossil fuels or wood residue fuels.

- Combinations of two or more of the above systems.

Steam Systems

Figure 4-1 illustrates a typical steam heat exchanger connected to a dryer. This system is commonly used where steam is available and where drying does not require high temperatures. The upper temperature limit for inlet air to the dryer using steam as an energy source is generally 400°F. The cost of steam heat depends entirely on the fuel used to generate the steam at the boiler. If wood residue fuels are burned, the delivered cost of the energy may range from $0.50 to $0.75 per million Btu. If oil is burned, however, the delivered cost of the energy could easily exceed $2.00 per million Btu.[6] Steam-heated dryers are installed both as single units and as units connected in series. A distinct advantage of steam as an energy source is that the dryer exhaust gases contain no combustion products and emission levels will be lower than those from any alternative system, all other factors being equal.

Boiler Exhuast Systems

A rather recent modification to dryer systems is to connect them to the exhaust ducts from boilers. Typical exit temperatures for exhaust gases from boilers in particleboard/hardboard plants range from 400 to 625°F. The energy input from these exhaust gases of course depends on the temperature, moisture content, and flow rates of the gases. Even a small boiler can contribute several million Btu per hour to a particle dryer. A large boiler installation may supply up to 100 percent of the required energy.

Connection to boiler exhaust ducts has both positive and negative aspects. The primary advantage is in fuel savings at the dryers. A well-balanced system may save from $50,000 to $100,000 per year in dryer fuel costs if the boiler exhaust can be used to replace fossil fuels. On the negative side, first the products of combustion from the boiler stack will enter the dryer. Most of these leave in the dryer exhaust system and add to the pollutant emissions. The boiler (by itself) may be in compliance, as may the dryer, but when these units are connected, the resultant system will probably fail to comply with emission limits. Most regulatory agencies make no provisions in the emission regulations to promote such energy-conserving systems.

In addition to the emissions problem, other technical problems are encountered in connecting boilers to dryers. For most boilers the steam demands fluctuate, and thus so do the stack gas flow rates. Auxiliary fuel systems may therefore be required to maintain the required energy input to the dryers. Further, if the boiler is fired with wood and bark residues, emissions from the boiler may contain significant amounts of unburned carbon.[5] This could reduce the quality of the particles or fibers being dried, principally through unwanted addition of carbon to the furnish. Also, entry of burning carbon particles into the dryer could cause fires and/or explosions.

Direct-Fired Dryers

The most common method of energy input to fiber and particle dryers is through direct combustion of fuels in the heat energy input system. Two principle types of fuels are used: (1) fossil fuels, including natural gas, butane, propane, diesel oil, and/or heavier residual oils; and (2) wood residue fuels, including hogged wood and bark but principally sanderdust. Since these fuels undergo combustion, their use results in the products of combustion entering and leaving the dryer. These combustion products are principally gases (CO_2, H_2O, N_2, O_2), but may also include solid particles known as fly ash, the inorganic component of the fuel that does not burn. Gaseous and liquid fossil fuels produce neglible amounts of fly ash, but emissions from some residual oils and certainly from wood residue fuels may be significantly high.[5]

Fossil fuels have become almost prohibitively expensive for use in drying wood. Plants still using these fuels are making every effort to find alternative energy sources, particularly those burning natural gas. Although it is the least expensive of the fossil fuels, industrial curtailments on interruptible contracts have been increasing, and in many parts of the country natural gas is available less than 50 percent of the time.

There is a steady trend toward the use of sanderdust as fuel for dryers. Where it is available in reasonable quantities, it has proved economical and relatively easy to handle on a continuous basis. Precautions must be taken to limit dust emissions in transmission and storage of sanderdust. Its explosive character is well documented. A pilot light, usually with natural gas, must be maintained at all times in the sanderdust burner to prevent flameout.

Use of wood residue fuels other than sanderdust is not technically difficult but does require significant pretreatment to control both moisture and particle size distribution of the fuel. Problems in the use of wood residue fuels result principally from lack of fuel preparation and/or lack of control of the combustion process. Properly handled, wood residues can provide an excellent alternative fuel source.

Combined Energy Sources

Since the energy "diet" for a plant is based on availability and relative costs of alternative energy sources, each plant will attempt to maintain production with the least overall cost. As a result, steam-heated dryers are often used with natural gas as an auxilliary fuel and the capability to burn propane or diesel oil as a standby. Other combinations of energy sources for the dryer may be feasible.

5. EMISSIONS OF POLLUTANT MATERIALS FROM PARTICLE DRYER SYSTEMS

This section describes the particulate and gaseous emissions from particle dryers, the methods of measuring emissions, and the factors that affect the pollutant emission levels.

Pollutant materials emitted to the atmosphere are classed as gaseous and particulate pollutants. Common gaseous pollutants include sulfur dioxide, oxides of nitrogen, reduced sulfur compounds, and carbon monoxide. Particulate pollutant materials occur in the solid or liquid state and are defined as

> "... any matter, except uncombined water, which exists as a liquid or solid at standard conditions."[12]

Standard conditions* are defined as:

> "... a temperature of 60° Fahrenheit and a pressure of 14.7 pounds per square inch absolute."[12]

It is important to note that the definition of particulate pollutants to include "any matter" encompasses all possible materials that might be emitted to the atmosphere, with the exception of uncombined water.

POLLUTANT EMISSIONS FROM PARTICLE DRYERS

Emissions from particle dryers include both gaseous and particulate materials. Gaseous materials include principally gaseous combustion products (CO, CO_2, NO, NO_2, N_2, O_2, H_2O, etc.) plus the carrier air stream. These emissions are not considered to represent an environmental hazard, and regulatory agenices have taken no steps toward either measurement or control.

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* There is considerable variability among various agencies with respect to temperatures selected for "standard conditions." Oregon DEQ uses 70°F., Lane Regional APA (Eugene, Oregon) uses 60°F. Some agencies specify 60°F, or 20°C.

Particulate emissions from particle dryers are regarded by control agencies as a source of environmental concern. Though not clearly defined in terms of collected data, these emissions may be classified in two distinct groups: large particles and small particles.

Large-Particle Emissions

Large particles may be loosely considered as any particles whose diameter is greater than 10 microns.* Almost all large particles emitted from dryers are wood fibers. These fibers enter the dryer as "fines" and are too small to be collected in primary cyclones. Thus, they are emitted to the atmosphere in the cyclone exhaust gas stream. Mean particle size of typical fiber emissions ranges from 20 to 50 microns. When dryer systems are uncontrolled, most of the materials emitted to the atmosphere consist of large particles. Concern over fiber particles resulted in promulgation of Oregon's regulations pertaining to particleboard and hardboard processing plants.[7]

Small-Particle Emissions

Small particles, those of diameter less than 10 microns, can be conveniently discussed in terms of two subgroups: solid particles and volatile organic particles.

Solid Particles - Solid particles are products of two processes, combustion and use of additives. Dryers heated by exhaust gases from boilers and dryers heated directly by burning of fossil fuels or wood residue fuels both emit the products of combustion. The particulate products of combustion are inorganic fly ash (the noncombustible portion of the fuel) and fixed carbon, which results from incomplete combustion.

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* One micron is equal to 10^{-6} meters (or 1 micrometer).

The second process that generates solid particles is the addition of adhesive resins to the particle furnish prior to the drying operation. In theory, small resin particles passing through the dryer will escape from the cyclone. This is speculative, however, since no definitive measurements have shown that resin particles actually do make up a portion of the solids emitted by dryers. Further, the amount of such emissions is undoubtedly very small relative to other emissions from the dryers.

Volatile Organic Particles - This second subgroup of small particles emitted by dryers constitutes a very real problem, which can be explained theoretically in terms of the three principle components of wood:

- Lignin - The characteristic cementing constituent between the walls of the cells of woody tissues. Lignin is a brownish substance whose exact chemical composition is unknown.
- Cellulose - The chief substance composing the cell walls of wood. Cellulose is a carbohydrate represented by the empirical formula $(C_6H_{10}O_5)_x$.
- Hemi-Cellulose - Any of a group of complex carbohydrates that surround the cellulose fibers of plant cells. Hemi-celluloses have no chemical relationship to cellulose.

When wood is placed in a high-temperature atmosphere for drying, the volatile portion of these organic materials may evaporate and enter the gaseous phase. In addition to the physical process of evaporation, chemical changes may also occur through pyrolysis and oxidation. The result is that a mixture of gaseous organic materials and inorganic water vapor may be present in the dryer.

As the gas mixture proceeds through the dryer system, the temperature gradually decreases. High-molecular-weight gases begin to condense when the temperature reaches 360 to 400°F. Lower-molecular-weight gases condense at lower temperatures. Very light molecules may remain in the gaseous state as the dryer exhaust enters the atmosphere and is cooled to ambient temperatures.

The condensation products of the organic gases are thought to be principally in the liquid state. This is not clearly defined, since the substances having very high molecular weight may condense to form a viscous liquid, which approaches the physical characteristics of a solid at ambient temperatures. Whether liquid or solid, the condensation products are presumed to be submicron in size, perhaps about 0.5 micron in diameter. They are further presumed to be essentially spherical and subject to the classical laws of physics. These comments, as noted earlier, are theoretical. Laboratory work has shown that wood constituents are definitely volatile in part. Volatility is species-dependent and, of course, highly temperature-dependent. In any case some of the organic components of wood are known to be volatile.

It is also known that organic materials in the gaseous state can condense to form discreet particles. Again, there is considerable temperature dependency as well as functional dependence upon the molecular weight and concentration of the gaseous substance. Thus, one can conclude from consideration of these known physical phenomena that small particles of condensed organic materials can be expected in the exhaust gas streams of some wood particle dryers.

Supporting evidence for this conclusion was provided in a study of emissions generated in the drying of sheets of wood in veneer dryers, which demonstrated the presence of volatile organic materials.[1] In that the process of drying veneer is similar to the process of drying wood particles or fibers, one could conclude that emissions from wood particle dryers may, under certain conditions, contain condensed or condensable organic compounds.

Emission tests of particle dryers have demonstrated the presence of condensable materials, other than water, in some exhaust gas streams. These condensable materials are soluble in organic solvents. No accurate determinations of their molecular structures have been made.

Although it is common practice within industry and regulatory agenices to refer to the volatile organic constituents of particle dryer exhaust gases as "hydrocarbons," this is a misnomer. There is no theoretical basis for assuming the presence of organic materials whose molecular structures are limited to atoms of hydrogen and carbon. Further, there are no test data that suggest that these materials are either principally or exclusively hydrocarbons or even that they contain trace amounts of hydrocarbons.

By way of summary, dryer emissions may be of three different categories: 1) large particles composed principally of fibers; 2) small inorganic particles; 3) small organic particles. Both the inorganic and the organic small particles may form the characteristic blue haze associated with fiber and particle dryers. Attention is now focused on the methods of measuring emissions.

MEASUREMENT OF PARTICLE DRYER EMISSIONS

Measurement of emissions from particle dryers involves several techniques specific to the parameters being measured. The primary parameters of concern are:

Concentration	(gr/sdcf)
Mass emission rate	(lb/hr)
Opacity	(%)

Occasionally, size distribution of the particles is determined.

Measurements of concentration and mass emission rates are closely related. Determination of the mass emission rate is based on knowing the concentration of particles and the flow rate of gases from the system in accordance with the formula:

$$\begin{matrix}\text{Mass emission} \\ \text{rate (lb/hr)}\end{matrix} = 0.00857 \times \begin{matrix}\text{concentration} \\ \text{(gr/sdcf)}\end{matrix} \times \begin{matrix}\text{gas flow rate} \\ \text{(sdcfm)}\end{matrix}$$

Techniques for determination of concentration have been the source of considerable disagreement. The methods and their limitations are briefly summarized below.

The Hi-Volume Method

In April 1972 the Oregon DEQ issued a document entitled Standard Sampling Method for Determination of Particulate Emissions from Cyclones. The procedure described involves a noncondensing sampling train in which the sample is collected isokinetically and is drawn through a large glass-fiber filter. Gas flow rates through the hi-volume sampler typically range from 20 to 50 cfm. Particles collected on the filter are analyzed gravimetrically, and emission concentrations are calculated on the basis of the mass of collected sample and the volume of air sampled.

In most particle dryers exhaust gases leave the primary cyclone, particularly in uncontrolled systems. Since the emissions emanate from cyclones, the hi-volume method was considered to be applicable.

Advantages of the hi-vol method include the ability to gather large samples in a relatively short period of time and the ability to gather several samples from the same source and thus to facilitate statistical analyses to determine normal variations about the mean concentration. In terms of application to particle dryers specifically, the greatest limitation of the method is that it involves a noncondensing train. Regulatory agencies define particles as materials that exist as liquids or solids at standard conditions. The temperatures at the filter in a hi-vol train may well be above standard temperatures. Thus, agencies are concerned that condensable organic materials may not have condensed by the time they pass through the filter. Since they would not be caught in the train and included in the measured concentrations, results would tend to indicate lower-than-actual concentrations, considering the definition of the term "particulate."

The S-8 Method

In September 1972 the S-8 Source Test Committee of the Pacific Northwest International Section of the Air Pollution Control Association published a Source Test Procedure for Determination of Particulate Emissions from Veneer Dryers. This procedure utilizes a condensing sampling train. Isokinetically collected samples are passed through an initial filter, a set of condensing impingers, and a final filter to collect all of the condensable materials that might be emitted from the dryers. The procedure was developed in response to the recognition that emissions specific to veneer dryers consist principally of condensable water vapor and volatile organic materials.

Because the procedure involves low rates of sample gas flow, in the range of 1 cfm, only small volumes of gas can be sampled during a normal run. Further, the train involves many components and often is difficult to seal against leakage in field operations. Because of the sample time required and complexity of the equipment, few replicative tests are taken to determine variations about the mean. Although it is difficult to collect representative samples from cyclone exhaust systems, the system is adequate for sampling of veneer dryer vents.

The EPA Method 5

The U.S. Environmental Protection Agency, in the Federal Register of December 23, 1971, published the much-used "Method 5." This procedure was designed for determination of concentration of particulate materials specific to large, fossil-fuel-fired steam generating boilers. Through an evolutionary process it has come to be accepted by many regulatory agencies as appropriate for determination of particulate concentrations from a wide variety of sources. It involves isokinetic collection of the sample gas stream in a heated probe. Gases are passed through a heated glass-fiber filter and then to a series of impingers. There is no final filter downstream from the impingers. The system entails low gas flow rates, similar to those of the S-8 Method.

The heated probe and filter prevent condensation of the volatile organic constituents of the sample in the probe and the filter. The aerosol condensates are collected in the impinger portion of the sampling train. The analytical procedures would have to be modified to include an extraction for organic determination (i.e., option available in the S-8 Method).

SELECTION OF MEASUREMENT TECHNIQUE

Selection of a measurement technique for particle dryer emissions is somewhat discretionary. Requirements of the Oregon DEQ under OAR 20-040 are as follows:[12]

1) Any sampling, testing or measurement performed under this regulation shall conform to methods on file at the Department of Environmental Quality or to recognized applicable standard methods approved in advance by the Department.

2) The Department may approve any alternative method of sampling provided it finds the proposed method is satisfactory and complies with the intent of these regulations and is at least equivalent to the uniform recognized procedures in objectivity and reliability, and is demonstrated to be reproducible, selective, sensitive, accurate, and applicable to the program.

On October 18, 1974, the Director of the DEQ issued a letter to all consultants stating as follows:

> "In January 1973 the Department developed a standard Source Test Procedure for Veneer Driers. Some consultants have used this method on wood particle dryer tests, while others have used the boiler test method. To assure comparable results in the future, the Veneer Dryer Method will be required on all of bark and wood particle dryers, since a large percentage of the emissions is expected to be hydrocarbons."

Of the source test results made available to this study on particle dryers located in Oregon, 60 percent of the tests were made with the hi-vol method, 35 percent with the S-8 Method, and 5 percent with the EPA Method 5.

The Department of Natural and Economic Resources, Office of Water and Air Resources, the State of North Carolina, regulates selection of the testing method as follows:

Regulation No. 6, Paragraph 6.4:[13]

> "Testing to determine compliance shall be in accordance with methods approved by the Board of Water and Air Resources."

OPACITY

Visual determination of compliance with applicable opacity regulations is made by following procedures first published in this country by the U.S. Bureau of Mines, Information Circular 8333. This method entails the use of the Ringelmann chart for discriminating the degree of shade or density of visible emissions. The opacity concept evolved from the effective use of the Ringelmann chart in quantitating dense smoke emissions. Opacity regulations are commonly enforced throughout this country. The principles and procedures are stipulated in EPA Test Method Number 9, Federal Register, Volume 36, Number 247, Thursday, December 23, 1971.

Under atmospheric conditions and production methods that promote condensation of water vapor in the exhaust gas stream, the gas stream frequently appears as billowing white plumes. The presence of significant quantities of condensed water vapor often makes it difficult to obtain accurate estimates of the opacity of the exit gas stream. The large particles in the gas stream are typically light brown or beige, the color of wood fibers. The small particles, because of their effect on the scattering of incident light rays, typically appear as blue. "Blue haze" is the principal source of opacity in particle dryer plumes.

FACTORS AFFECTING EMISSIONS FROM UNCONTROLLED DRYERS

Large-Particle Emissions

Fiber emissions from particle dryers are influenced by a variety of parameters, some related to the drying process and some to system design. Some of the more significant factors are listed and discussed briefly below.

1. Percentage of fines in the particle furnish to the dryer. Cyclone collection efficiency depends on the size distribution of materials handled in the system. If a large percentage of fine materials enter the cyclone, then one would expect a significant portion of those fines to be entrained in the exhaust gas stream from the cyclone.

2. Feed rate of materials through the dryer and cyclone. The total amount of material handled by the cyclone also strongly affects fiber emissions. As feed rate of material through the system increases, so does the concentration of materials in the exhaust gas stream.

3. Gas flow rates through the cyclone. Cyclone collectors are designed to operate at optimum efficiency within a certain range of gas flow rates. If the flow rates exceed the design range or fall significantly below it, collection efficiency will be reduced, with greater amounts of fibers being entrained in the exhaust gas stream.

4. Moisture content of the exhaust gases. High levels of moisture in exhaust gases tend to add to the collection efficiency of cyclones handling fine materials, perhaps because of an agglomerating effect of the moisture. Not all materials, however, are affected beneficially, as are wood fibers.

5. Addition of adhesive resins to the particle furnish prior to drying. Agglomeration of the fiber particles to prevent entrainment in the cyclone exhaust gas stream can also be effected by the addition of resins before the dryer. Since the cost of resins is a major business expense, however, loss of 1 percent of the resins through entrainment in the dryer exhaust can be very expensive.

6. Design of the cyclone. Design of the cyclone system is perhaps the most important of the variables affecting

emissions of large particles. A well-designed system will provide significantly higher collection efficiency on fiber particles than a poorly designed system.

7. Design of the fan system. Uniformity of gas flow through a cyclone is influenced by a fan design. A centrifugal fan with only four or six blades sends a pulsating gas flow through the system, tending to make the return vortex in the cyclone unstable and consequently to increase entrainment of particles in the exhaust gas stream. Centrifugal fans with 12 to 16 blades greatly reduce the pulsations in the system. The rpm of the fan system also influences the degree of pulsation.

Small-Particle Emissions

The primary cyclones in dryer systems are designed to separate wood fibers and particles from the carrier air stream. These units are generally effective for collection of particles whose mean size is larger than 50 to 100 microns. They are not effective, however, for particles whose size range is less than 10 microns. Any small particles that enter the dryer or that are generated in the dryer or in the energy source for the dryer will leave the primary cyclone in the exhaust gas stream as pollutant materials. The factors that influence the quantity of small particles are as follows.

1. The energy source for the dryer. If the dryer is heated with exhaust gas from a boiler or is direct-fired, the products of the combustion process will include small particles.* The inorganic ash content of the fuels is most

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* The amount of small particles generated by the combustion of natural gas, propane, or butane probably is negligible because of the lack of inorganic, noncombustible materials in these fuels. Any incomplete combustion of the fuels, however, generates fixed carbon particles.

significant. Wood, for example, contains up to 2.5 percent inorganic ash.*[6] If sanderdust is burned as an energy source, the concentration of particles prior to dilution will be more than 2.0 gr/sdcf. With normal dilution, the fly ash from sanderdust combustion can still exceed 0.20 gr/sdcf at the cyclone exit.

2. Species of furnish. The volatile organic materials that contribute to the presence of small particles vary significantly with wood species. Douglas fir contains significant amounts of haze-forming volatile materials, whereas white firm emits small amounts of such materials when processed in the same manner. No summary data are available concerning the influence of species on volatile organic emissions.

3. Rate of moisture removal. The drying rate depends principally on the amount of moisture to be removed and on residence time. If the furnish is fed to the dryer at 12 percent moisture (dry basis) and must be dried to 5 percent, the amount of water to be evaporated is relatively small and correspondingly low inlet temperatures to the dryer can bring about the required results with little or no evaporation of the volatile organic components of the wood. Conversely, if the inlet moisture level is 200 percent and must be reduced to 5 percent in a single step, very high inlet temperatures are required. These high temperatures cause evaporation of significant amounts of volatile organic wood components.

Rate of moisture removal is also a function of residence time. A very large dryer handling a small mass flow of material can provide enough residence time for the materials to dry at moderate temperatures. Small dryers receiving as much furnish as the pneumatic or mechanical systems can push through provide little residence time for any single particle. Under these conditions, high temperatures are required to dry the materials quickly, with resulting high concentrations of haze-forming emissions.

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* The ash content of wood can range from 0.5 to 1.0 percent. Bonding resins used in particleboard production may increase the inorganic ash content of sanderdust to 2.5 percent.

Although there is a tendency to conclude that the temperature is the key to organic emissions, temperature of the system is a dependent variable. Moisture differentials and feed rates through the dryers are relatively independent process variables. The average temperature does influence the amount of blue haze formed, but temperature cannot be adjusted arbitrarily. The operator can, however, adjust the process in terms of the required changes in moisture levels per dryer stage and in terms of the feed rates through the dryers and thereby can control the temperature requirement for drying.

The factors that influence the emission of particles from dryers may be summarized in terms of the elements of an effective dryer system:

- The furnish consists of large particles only.
- The furnish is fed at nominal rates through the primary cyclone.
- Gas flow rates through the cyclone are kept within the design range.
- Moisture levels of the gas stream in the cyclone are kept relatively high.
- The cyclone is designed as a high-efficiency unit.
- The fan is designed for minimum pulsation of air flow through the cyclone.
- The dryer energy source is steam-heated coils.

- The species to be dried is white fir.
- Moisture levels of the furnish are kept relatively constant.
- The residence time in the dryer is adequate for drying at low temperatures.

In an installation like this, emission levels for the "uncontrolled" cyclone were measured at less than 0.02 gr/sdcf and the opacity was 0 percent. Dryer Nos. 30 through 33, as listed in Appendix D, incorporate these performance characteristics.

6. REGULATIONS PERTAINING TO PARTICLE DRYER EMISSIONS

Several categories of regulations pertaining to particle and fiber dryers are currently in effect. The regulations promulgated by the various states may vary significantly; specific regulations are cited herein as examples, but are not to be construed as typical of or applicable to other jurisdictions. It is recommended that the appropriate state regulations be consulted to determine emission limits applicable to the jurisdiction in which a plant is located.

PROCESS WEIGHT REGULATIONS

On March 5, 1971, the Oregon Environmental Quality Commission (EQC) adopted process weight emission standards for particleboard and hardboard plants located within the jurisdiction of the Department of Environmental Quality (DEQ). The levels adopted were based on the following approach:

> "After evaluating a considerable amount of data, sampling results from three fully-tested Oregon (particleboard) plants were selected for detailed analysis. For each one, the high-emitting cyclones and their existing emissions were grouped and totalled. The emissions for the 6-8 highest emitters were reduced by 90% and a new plant-site total calculated. The resultant emission, divided by the plants' hourly production capacity, represented a lbs/M sq. ft. emission level achievable by the hypothetical control program ... the range of controlled emissions ranges from 1.9 to 2.8 lbs/M sq. ft. ... The emission standard of 3.0 lbs/M sq. ft. was adopted by the ... Commission..."[7]

In the account of development of the regulation,[7] no mention is made of haze or blue haze; neither is there mention of organic materials, volatile organics, condensables, or hydrocarbons. The primary emphasis in promulgating Oregon's regulations for emissions based on process weight of plant production is on controlling fiber emissions, principally from cyclones handling sanderdust and from particle dryers.

OAR 25-320 (2) (a) (for particleboard):[12]

> No person shall cause to be emitted particulate matter from particleboard plant sources including, but not limited to, hogs, chippers, and other materials size reduction equipment, process or space ventilation systems, particle dryers, classifiers, presses, sanding machines, and materials handling systems, in excess of a total from all sources within the plant site of three (3.0) pounds per 1000 square feet of particleboard produced on a 3/4 inch basis of finished product equivalent.

OAR 25-320 (2) (b):

> Excepted from subsection (a) are truck dump and storage areas, fuel burning equipment, and refuse burning equipment.

OAR 25-325 (2) (a) (for hardboard):

> No person shall cause to be emitted particulate matter from hardboard plant sources including, but not limited to hogs, chippers, and other material size reduction equipment, process space ventilation systems, particle dryers, classifiers, presses, sanding machines, and materials handling systems, in excess of a total from all sources within the plant site of one (1.0) pound per 1000 square feet of hardboard produced on a 1/8 inch basis of finished product equivalent.

OAR 25-325 (2) (b)

> Excepted from subsection (a) are truck dump and storage areas, fuel burning equipment, and refuse burning equipment.

It is important to note that the process weight regulations are not applied directly to individual dryers. The dryer emissions are included in the total of emissions from all sources within the process plant. Thus, even though the dryers could be well-controlled in every respect, the plant could still fail to meet process weight limitations because of emissions from sources other than dryers.

When the Oregon EQC adopted the standards for particleboard and hardboard plants, they also adopted standards for veneer and plywood processing plants. Emissions from veneer dryers are not included in the process weight limitations placed on plywood operations. Particle dryer emissions, however, are included in the limitations for particleboard and hardboard plants. Undoubtedly this difference results from the recognition at that time that veneer dryers do not contribute to emissions of fibers, whereas particle dryers do.

Information supplied by the U.S. EPA indicates that the Oregon regulations are not typical of most states with respect to process weight restrictions. California, Georgia, Kentucky, Mississippi, North Carolina, and South Carolina have adopted process weight emission standards patterned after those set originally in California. The North Carolina regulations, perhaps the most typical, are indicated below:[13]

> 2.30 Control and Prohibition of Particulate Emissions From Miscellaneous Industrial Processes
>
> No person shall cause, suffer, allow, or permit particulate matter caused by industrial processes for which no other emission control standards are applicable to be discharged from any stack or chimney into the atmosphere in excess of the rates shown in Table I.

Table I. NORTH CAROLINA REGULATION 2.30
ALLOWABLE RATE OF EMISSION BASED ON ACTUAL PROCESS WEIGHT RATE

Process weight rate		Rate of emission	Process weight rate		Rate of emission
Lb/hr	Ton/hr	Lb/hr	Lb/hr	Ton/hr	Lb/hr
100	0.05	0.551	16,000	8	16.5
200	0.10	0.877	18,000	9	17.9
400	0.20	1.40	20,000	10	19.2
600	0.30	1.83	30,000	15	25.2
800	0.40	2.22	40,000	20	30.5
1,000	0.50	2.58	50,000	25	35.4
1,500	0.75	3.38	60,000	30	40.0
2,000	1.00	4.10	70,000	35	41.3
2,500	1.25	4.76	80,000	40	42.5
3,000	1.50	5.38	90,000	45	43.6
3,500	1.75	5.96	100,000	50	44.6
4,000	2.00	6.52	120,000	60	46.3
5,000	2.50	7.58	140,000	70	47.8
6,000	3.00	8.56	160,000	80	49.0
7,000	3.50	9.49	200,000	100	51.2
8,000	4.00	10.4	1,000,000	500	69.0
9,000	4.50	11.2	2,000,000	1,000	77.6
10,000	5.00	12.0	6,000,000	3,000	92.7
12,000	6.00	13.6			

Interpolation of the data in this table for process weight rates up to 60,000 lbs/hr shall be accomplished by use of the equation $E = 4.10\ P^{\circ(.67)}$, and interpolation and extrapolation of the data for process weight rates in excess of 60,000 lbs/hr shall be accomplished by use of the equation:

$$E = [55.0\ P^{\circ(.11)}] - 40$$

Where E = rate of emission in lb/hr and

P° = process weight rate in ton/hr.

> Process weight per hour means the total weight of all materials introduced into any specific process that may cause any emission of particulate matter. Solid fuels charged are considered as part of the process weight, but liquid and gaseous fuels and combustion air are not. For a cyclical or batch operation, the process weight per hour is derived by dividing the total process weight by the number of hours in one complete operation from the beginning of any given process to the completion thereof, excluding any time during which the equipment is idle. For a continuous operation, the process weight per hour is derived by dividing the process weight for a typical period of time.

It may be seen that North Carolina's process weight regulations for emissions from miscellaneous processes covers a broad spectrum within which particleboard and hardboard plants and particle dryers may be included; whereas Oregon maintains a regulation specifically directed toward particleboard and hardboard manufacturing operations.

REGULATIONS PERTAINING TO CONCENTRATION OF POLLUTANT EMISSIONS

In addition to process weight limitations for particle and fiber panel production facilities, individual particle dryers are subject to limits on the concentration of particle emissions. On February 15, 1972, the Oregon DEQ adopted the following regulation:[12]

> OAR 21-030 PARTICLE EMISSION LIMITATIONS FOR SOURCES OTHER THAN FUEL BURNING AND REFUSE BURNING EQUIPMENT
>
> (1) No person shall cause, suffer, allow or permit the emission of particulate matter, from any air contaminant source other than fuel burning equipment or refuse burning equipment in excess of:
>
> (a) 0.2 grains per standard cubic foot for existing sources, or

(b) 0.1 grains per standard cubic foot for new sources.

These restrictions are typical of concentration regulations of most states. An additional set of restrictions is placed on particle dryers whose energy source systems include direct combustion of fuels. The Oregon DEQ adopted the following regulation on May 22, 1970:[12]

OAR 21-020 FUEL BURNING EQUIPMENT LIMITATIONS

No person shall cause, suffer, allow, or permit the emission of particulate matter, from any fuel burning equipment in excess of:

(1) 0.2 grains per standard cubic foot for existing sources, or

(2) 0.1 grain per standard cubic foot for new sources.

Few states consider direct-fired dryers to be in the category of fuel burning equipment. At present North Carolina has no regulation pertaining to concentrations of particulate emissions.

REGULATIONS PERTAINING TO OPACITY

Within the regulations of the Oregon DEQ, opacity is covered by the following provisions:[12]

OAR 21-015 VISIBLE AIR CONTAMINANT LIMITATIONS

(1) Existing Sources Outside Special Control Areas. No person shall cause, suffer, allow, or permit the emission of any air contaminant into the atmosphere from any existing air contaminant source located outside a Special Control Area for a period or periods aggregating more than 3 minutes in any one hour which is:

(a) As dark or darker in shade as that designated as No. 2 on the Ringlemann Chart, or

(b) Equal to or greater than 40% opacity.

(2) New Sources in All Areas and Existing Sources Within Special Control Areas: No person shall cause, suffer, allow or permit the emission of any air contaminant into the atmosphere from any new air contaminant source, or from any existing source within a Special Control Area, for a period or periods aggregating more than 3 minutes in any one hour which is:

   (a) As dark or darker in shade as that designated as No. 1 on the Ringelmann Chart, or

   (b) Equal to or greater than 20 percent opacity.

(3) Exceptions to 21-015 (1) and 21-015 (2).

   (a) Where the presence of uncombined water is the only reason for failure of any emission to meet the requirements of Section 21-015 (1) and 21-015 (2), such sections shall not apply.

   (2) Existing fuel burning equipment utilizing wood wastes and located within Special Control Areas shall comply with the emission limitations of Subsection 21-015 (1) in lieu of Subsection 21-015 (2).

Note that, with the exception of uncombined water vapor, this regulation applies to any material emitted to the atmosphere that results in opacity levels in excess of the standards. The following opacity regulations promulgated by North Carolina, although similar to those of Oregon, may be somewhat more representative of the format of typical requirements.

Regulation No. 2 - Control and Prohibition of Visible Emissions

2.0 Purpose

The intent of this regulation is to promulgate rules pertaining to the prevention, abatement and control of emissions generated as a result of fuel burning operations and other industrial processes where an emission can be reasonably expected to occur, except during startups made in accordance with procedures approved by the Board.

2.1 Scope

This regulation shall apply to all fuel burning installations and such other processes as may cause a visible emission incident to the conduct of their operations.

2.2 Restrictions Applicable to Existing Installations

No person shall cause, suffer, allow or permit emissions from any installation which are:

(1) Of a shade or density darker than that designated as No. 2 on the Ringelmann Chart for an aggregate of more than 5 minutes in any one hour or more than 20 minutes in any 24-hour period or

(2) Of such opacity as to obscure an observer's view to a degree greater than does smoke described in paragraph 2.2, subparagraph 1.

(3) All existing sources shall be in compliance with the provisions of Paragraph 2.3 within 5 years.

2.3 Restrictions Applicable to New Installations

No person shall cause, suffer, allow or permit emissions from any installation which are:

(1) Of a shade or denisty darker than that designated as No. 1 on the Ringelmann Chart for an aggregate of more than 5 minutes in any one hour or more than 20 minutes in any 24-hour period, or

(2) Of such opacity as to obscure an observer's view to a degree greater than does smoke described in paragraph 2.3, subparagraph 1.

2.4 Where the presence of uncombined water is the only reason for failure of an emission to meet the limitations of paragraph 2.2 and 2.3 those requirements shall not apply.

OTHER APPLICABLE REGULATIONS

The primary regulations applied to particle and fiber dryers are those already outlined (process weight, concentration, and opacity). Other regulations that might be applied but are not generally considered in regard to these process industries include nuisance regulations, general "catch-all" regulations, and regulations pertaining to the size of particles that may be emitted from a process or plant.

Two additional classes of regulations that could have considerable impact on the particle and fiber processing industries are those pertaining to emission sampling and to "general provisions." With respect to emission sampling, most agencies require that upon request the owners or operators of process equipment shall make or have made a source test and shall submit a report to the agency director. Because of the high cost often entailed in performing the prescribed test procedures, such regulations can result in significant costs to industry. Most agencies have applied these regulations carefully and have required tests only when they were believed necessary. As a result, some of the particle and fiber dryers having very low visible emissions have not been tested, whereas others whose visible emissions indicate potentially significant contaminant input to the atmosphere have been tested.

Regulations identified as "general provisions" also can have a large impact on particle and fiber drying processes. The Oregon DEQ under OAR 25-310 (4) states as follows:[12]

> Upon adoption of these regulations, each affected veneer, plywood, particleboard, and hardboard plant shall proceed with a progressive and timely program of air pollution control, applying the highest and best practicable treatment and control currently available ...

The phrase "...highest and best practicable treatment and control..." is fairly common in control agency regulations. Some agencies have been accused of misusing the concept. It is admittedly difficult to apply to technically complex systems. However, it is an effective way of advancing the universal application of the state-of-the-art of control technology.

North Carolina's emission control standards contain a similar requirement:

Section IV, paragraph 1:[13]

> ..."All sources shall be provided with the maximum feasible control."

7. APPLICATION OF CONTROL TECHNOLOGY TO MEET EMISSION REGULATIONS

In responding to the regulations relative to particle and fiber dryers, industry members have applied several types of emission control devices. In this section these devices are described and evaluated in terms of effectiveness, cost, and operational problems.

WET SCRUBBER EMISSION CONTROL DEVICES

One of the first control devices to be applied in the industry was a wet scrubber system installed in southern Oregon. This system was successful in reducing emissions to acceptable levels.[3] All of the 19 wet scrubbers presently installed on fiber and particle dryers visited during this study were manufactured by the same company, and 18 of the 19 are of the same design and construction.

Success in Meeting Regulations

In terms of percentage, 95 percent of the scrubbers installed (18 of 19) are effectively keeping the dryer emissions in compliance. There are some important reasons for the high degree of success and for the single 'failure.' The scrubber installations, designated according to dryer numbers on the data sheets in Appendix D, are described in some detail in the following pages.

Dryers 4 through 7 are heated with steam in combination with natural gas. The input of small particles from the energy source is thus effectively zero. The normal input temperatures to the dryers range from 250 to 300°F, a range that precludes the formation of small particles due to volatile organic components of the wood. Therefore, the only particles that must be controlled are the large particles, the fibers, which are easily handled by any well-designed scrubber. As a result, operating opacity is zero and the particle concentrations are in compliance.

Dryers 13 through 20 are equipped with scrubbers that are not now in operation. The scrubbers have been demonstrated to be effective in controlling emissions, but emission levels are normally too low to justify the cost of operating the scrubbers. The emission levels are low because, as with dryers 4 through 7, these are low-temperature units heated with steam and natural gas. Since the maximum operating temperature is 480°F, volatile organic components are not released from the furnish. The primary cyclones are effectively engineered and operated within their design ranges. Thus the need for the wet scrubbers has not yet materialized. Should the plant decide to increase production levels and "push" the dryer capacity, operation of the scrubbers may be required.

Dryer 26 uses sanderdust, natural gas, and propane as its energy sources. With inlet temperatures of 550°F, some small particles are evaporated from the furnish. The sanderdust combustion generates other small particles but the scrubber is effective in controlling the combined input of small particles. The large fiber particles are easily caught in a scrubber, and the result is that the unit does meet the regulations. Under normal operation the opacity observed is less than 5 percent. There are occasional excursions opacity exceeds 20 percent; moisture content of the furnish requires higher inlet temperatures or when the furnish is predominantly wet Douglas fir. Generally, the unit is in compliance.

Dryer 27 uses the same energy sources as Dryer 26 but operates at lower inlet temperatures. As a result, less volatile material is evaporated from the wood and opacity is lower. Again, the scrubber is effective in keeping the emissions in compliance.

Dryers 40 and 41 are heated with steam and natural gas. Dryer 43 is heated with steam and hot water only. Inlet temperatures for these dryers seldom exceed 200°F. With these temperatures and energy sources, the only particles entering the scrubber are fibers that are easily controlled.

Dryer 42 receives all of its energy input from a boiler fired with wood and bark residues. Inlet temperatures range from 450 to 500°F. Under these conditions, fine particles from the boiler represent a significant input to the system and the heat drives off some volatile organic components. With this combined input of fine particles plus the input of large particles, the scrubber must be highly efficient to keep the whole system in compliance. Although emissions from this scrubber are the highest in terms of concentration of any of the installed units (0.071 gr/sdcf), the requirements are met. Opacity is not a problem since the input temperatures are not sufficiently high to drive off excessive amounts of volatile organic components.

Dryer 9 is equipped with a scrubber that is not completely effective and fails consistently to keep the dryer emissions in compliance. The energy source is a sanderdust-fired boiler, which produces fine particles in significant quantities. Further, the inlet temperatures to the dryer range from 400 to 700°F. Since most of the furnish is Douglas fir, the combination of high temperatures and high content of volatile organic compounds common to Douglas fir results in generation of many fine particles.

The input of fibers or large particles to the scrubber is relatively small, indicating a well-designed and -operated primary cyclone system. The resultant input to the scrubber then, is predominantly small particles, less than 1 micron in diameter and likely in the 0.5-micron range. Collection of submicron particles is difficult for mechanical collection devices. The scrubber performs consistently at the 70 to 75 percent level of efficiency. In doing so, it meets the requirements for concentration and for process weight, but does not consistently meet the requirements for opacity. The burden of fine particles to the system is too great, and the resultant blue haze is evident.

Summary data on wet scrubber control devices are given in Table 7-1.

Problems With Wet Scrubbers

Most industry representatives who operate wet scrubbers would rather not, for the following reasons:

1) The cost of installation and operation. Of the 19 units, 18 are low-energy systems with pressure differentials in the range of 3 to 8 inches H_2O. Even this relatively low level of energy input entails operating expense. By contrast, the system that fails to achieve compliance is a high-energy scrubber requiring 50 inches H_2O pressure drop, an energy input requiring costly electric usage.

2) Wet scrubbers usually convert an air pollution problem into a water treatment problem. With today's restrictions on wastewater discharge, operation of a typical scrubber system may entail as much capital for cleaning and recycling the water as for initial purchase of the scrubber. Unless the liquid handling system is well-engineered and properly installed, the liquid slurry generated in the scrubber can create a significant disposal and water pollution problem.

Table 7-1. SUMMARY OF WET-SCRUBBER CONTROL DEVICES FOR PARTICLE DRYERS

Dryer No.[a]	Energy sources		Inlet temp., °F	Primary species	Exit conc., gr/sdcf	Opacity, %	Status
	Primary	Secondary					
4	Steam	Natural gas	250-300	D. Fir/ hemlock	Unknown	0	Complies
5	Steam	Natural gas	250-300	D. Fir/ hemlock	Unknown	0	Complies
6	Steam	Natural gas	250-300	D. Fir/ hemlock	Unknown	0	Complies
7	Steam	Natural gas	250-300	D. Fir/ hemlock	Unknown	0	Complies
8	Steam	Natural gas	250-300	D. Fir/ hemlock	Unknown	0	Complies
9	Sanderdust	Natural gas	400-700	D. Fir/ hemlock	0.049	10-30	Fails in opacity
13	Steam	Natural gas	480 max	D. Fir/pine	Unknown	<10	Complies w/o scrubber
14	Steam	Natural gas	480 max	D. Fir/pine	Unknown	<10	Complies w/o scrubber
15	Steam	Natural gas	480 max	D. Fir/pine	Unknown	<10	Complies w/o scrubber
16	Steam	Natural gas	480 max	D. Fir/pine	Unknown	<10	Complies w/o scrubber
17	Steam	Natural gas	480 max	D. Fir/pine	0.08	<10	Complies w/o scrubber
18	Steam	Natural gas	480 max	D. Fir/pine	Unknown	<10	Complies w/o scrubber
19	Steam	Natural gas	480 max	D. Fir/pine	Unknown	<10	Complies w/o scrubber
20	Steam	Natural gas	480 max	D. Fir/pine	Unknown	<10	Complies w/o scrubber
26	Sanderdust	Natural gas	550	D. Fir/pine	0.02	<5	Complies
27	Sanderdust	Natural gas	350	D. Fir/pine	0.02	<5	Complies
40	Steam	Natural gas	200	Pine	0.023	<5	Complies
41	Steam	Natural gas	200	Pine	0.018	<5	Complies
42	Bark-fired	Boiler	450-500	Pine	0.071	<5	Complies
43	Steam	Hot H_2O	200	Pine	0.002	<5	Complies

[a] Additional information on these dryers is given in Appendix D.

3) Maintenance of the system can be costly. Liquid systems tend to corrode, erode, and most of all, to plug with great regularity. Some plant operators claim that as much as 1 1/2 man years per year are required to keep the scrubbers in operation.

Costs of Wet Scrubbers

Costs for installation of wet scrubbers cover a wide range. The first units installed were inexpensive, since the engineering and installation were done in-house. Cost is estimated at less than $1/cfm, based on early-1971 prices.[3]

In 1974 installations cost approximately $2.50/cfm. It is not known, however, whether this value includes all of the costs, i.e., engineering, purchasing, construction management, materials, startup, etc.

Typical costs reported by EPA for 1976 are $3 to $5 per cfm for turnkey jobs. Industrial estimates of the cost for a complete wet scrubber system including pumps, pipes, water recirculation system, water cleanup system, fiber handling system, engineering, purchasing, construction management, materials, and startup range from $5 to $7/cfm. For a typical particle dryer with gas flow rates of 30,000 cfm, this might represent a capital investment of $150,000 to $210,000.

Recommended Application of Wet Scrubbers

Experience to date indicates that wet scrubbers can be used effectively to control large particles and limited amounts of small particles. Their use for control of blue haze is not promising. With dryers whose energy sources are limited to natural gas, propane, butane, steam, and/or hot water, and whose maximum inlet temperatures do not exceed 500 to 550°F, wet scrubbers apparently can be used effectively to keep the system in compliance with regulations. Even with systems fired with sanderdust or the exhaust gases of boilers, wet scrubbers appear to be effective so long as the inlet temperatures are kept to reasonably low levels (less than 500°F) and/or the species dried is not high in volatile organic components (i.e., white fir). For systems operated outside of these restrictions, the success of wet scrubbers in controlling small particles is doubtful. Even with high-energy scrubbers, enough small particles may pass through the system to result in high opacity levels. Nevertheless, an important advantage inherent in control with scrubbers is their resistance to fire hazards.

FULL-RECIRCULATION CONTROL SYSTEMS

Seven full-recirculation systems have been installed on fiber and particle dryers in Oregon, with mixed results.

Dryers 1 and 2 are equipped with full-recirculation units. Dryer 2 is not yet complete. The performance of Dryer 1 is considered satisfactory and in compliance with all of the pertinent regulations.

Although Dryers 10 and 12 also are complying with the regulations, the concentration of emissions from Dryer 10 is closely approaching the limit of 0.1 gr/sdcf. Because full-recirculation units are considered as fuel burning devices, the control agency requires that emission levels be corrected to 12 percent CO_2.*

Dryer 11 has not yet demonstrated compliance and is faced with two independent problems. First, the sanderdust used to fire the system contains significant amounts of incombustible inorganic ash. The high ash levels result from the addition of salt compounds to the bonding resins in the panel products. These resins are picked up in the sanding operation and are incorporated into the sanderdust along with its normal inorganic ash content. When the sanderdust is burned, the ash becomes fly ash and increases the emission concentrations. Several plants using sanderdust as fuel have met the same situation. One plant solved the problem by changing the chemical makeup of their bonding resins. The change, however, increased the cost of the resins and therefore increased the product cost.

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* Many dryers employ direct combustion of fuels as an energy source. The control agencies have not considered these devices to be "fuel burning devices" nor required the correction to 12 percent CO_2 until the full recirculation systems came into use. At present at least one agency requires that the correction be made. In all probability, this does not result in a major adjustment to the emission concentration levels, since full-recirculation systems normally operate with low levels of excess air. The reasons for requiring the CO_2 correction on full-recirculation systems are not clear.

The second problem in operation of Dryer 11 entails high turndown ratios. Because this dryer is somewhat oversized, it must operate at low percentage rates of maximum capacity and cannot always maintain high temperatures in the combustion zone. At low levels of production, the system becomes unbalanced and incomplete combustion results. Plans are under way to improve the combustion controls to handle low-level production situations.

Dryers 28 and 29 also suffer from high ash content of the sanderdust and from high turndown ratios (wide flow-rate variations). During normal production they are considered to be in compliance with the regulations. They emit a blue haze because of the incombustible fly ash in the sanderdust, but the levels of opacity are typically in compliance (less than 20 percent). Table 7-2 presents summary data on full-recirculation control systems.

Success in Meeting Regulations

As noted above, full-recirculation systems enable dryer operators to meet the regulations of the agencies. The

Table 7-2. SUMMARY OF FULL RECIRCULATION CONTROL SYSTEMS

FOR PARTICLE DRYERS

Dryer No.[a]	Energy sources		Inlet temp., °F	Primary species	Exit conc., gr/sdcf	Opacity, %	Status
	Primary	Secondary					
1	Sanderdust	Hogged wood	800	D. fir	0.072	0	Complies
2	Sanderdust	Hogged wood	550	D. fir		0	Unknown
10	Sanderdust	Propane	800-1000	D. fir	0.121	<10	Unknown
11	Sanderdust	Propane	800-1000	D. fir	0.152	<10	Unknown
12	Sanderdust	Propane	800-1000	D. fir	0.08	<3	Complies
28	Sanderdust	Natural gas	800	D. fir/pine	0.09	<5	Complies
29	Sanderdust	Natural gas	600	D. fir/pine	0.08	<5	Complies

[a] Additional information on these dryers is given in Appendix D.

concentration regulations may be more restrictive for these systems if they are corrected for CO_2. Since all all of the full-recirculation systems are fired principally with sanderdust, which contains appreciable amounts of resin-based salts, the systems do emit substantial quantities of fine particles that form blue haze. Concentrations for each system tested closely approach the limit of 0.1 gr/sdcf. Under some operating conditions, such as high turndown ratios, the concentration limits may be exceeded.

Problems with the Systems

Full-recirculation systems are cost-effective only for mills that sand enough panels to generate the required sanderdust fuel. One of the systems is equipped with fuel preparation facilities that permit the use of hogged fuel (wood and bark residues) and the use of agricultural residues such as straw. Under these circumstances full recirculation may be economically attractive. The systems require additional capital investments for fuel preparation equipment.

Opacity in the exhaust gas stream is a major difficulty for at least one plant. Fine particles generated in the combustion process (fly ash) are not circulated through any other control devices; thus they contribute directly to opacity and also to borderline levels of concentration.

None of these systems has logged enough operating time to indicate the major operational problems. One might expect, however, that problems will be related to material handling of the fine-particle fuels and to control of the combustion system.

Dryers 24 and 25 are equipped with full-recirculation systems that are not used. These dryers are fueled with propane and natural gas. The cost of operating the systems as full-recirculation units is prohibitive.

Costs of Full-Recirculation Systems

Only two plants can provide information regarding costs of full-recirculation systems. Based on the number of dryers involved and the total package costs, it appears that conversion to this system costs $125,000 to $150,000 per dryer. At the installations evaluated, this cost was balanced by the high cost of fossil fuels, the alternative energy source. Conversion to wood residue fuels provided substantial returns on the investments.

Recommended Applications of Full-Recirculation Systems

Use of these systems is recommended only when there is an adequate supply of low-cost fuels such as sanderdust. They are prohibitively expensive to operate using fossil fuels.

For proper operation, high temperatures must be maintained in the combustion zone and the levels of dilution air fed to the dryer must be held low to minimize fuel usage. This results in high temperatures at the dryer inlet and correspondingly high levels of volatile organic emissions from the furnish. These high temperatures may further limit application should they result in degradation of particular furnishes or species.

Probably the most important potential limit on future application of full-recirculation systems is opacity due to inorganic fly ash from salt based bonding resins. For installations using sanderdust or other fuels containing high levels of inorganic ash, opacity will be a persisting problem. Pressure on the part of control agencies for nonvisible plumes may eventually require the use of baghouses, high energy scrubbers, or other control devices to collect the fine particles. Changing to salt free resins to limit the input of inorganic fly ash may be a practical solution.

PARTIAL-RECIRCULATION CONTROL SYSTEMS

Partial recirculation of exhaust gases from the primary cyclone to the combustion chamber on direct-fired dryers is done as much for economy as for emission control. The system can be effective for emission control, however, and should not be overlooked as a control alternative. Of the 76 dryers investigated in this study, 7 are equipped with what might be considered partial-recirculation systems installed for emission control purposes.

Dryers 49 and 50 can recycle up to 30 percent of the exhaust gases from the cyclones. The systems are identical in design and size and are used as predryers to reduce the moisture content of wet Douglas fir to the 15 to 18 percent level (dry basis). Inlet temperatures range from 600 to 900°F. At these high temperature levels one would expect significant amounts of fine particulate generated by the volatile organic components in the furnish. Both units are fired with sanderdust, with natural gas as an auxiliary fuel. The sanderdust also generates fine-particle fly ash.

The point of entry for the recirculated gas is downstream from the combustion chamber, where the oxygen concentrations are relatively low, probably less than 10 percent. Under these conditions, the potentially combustible volatile organic fine particles will not burn quickly, if at all. The result of this design is that opacity levels of emissions from these dryers frequently rise above 20 percent. Emission data on grain loading show values ranging from 0.09 to 0.20 gr/sdcf.

Dryers 59 and 60 are designed to recycle up to 40 percent of the exhaust gases from the cyclones; however, the gases do not return to the dryer combustion chamber. These dryers are fired with sanderdust, receive heat energy from boiler exhaust stacks, and have fuel oil backup. The dryer exhaust gases are passed through "skimmers," which remove most of the entrained particles. The pneumatic line from the skimmers carries up to 40 percent of the total dryer exhaust back to the boilers, where the combustible portion of the entrained particles is burned. Inlet temperatures to the dryers are 800°F. The furnish, however, is southern pine, which does not contain appreciable amounts of haze-forming volatile compounds. Opacity from the nonrecycled portion of dryer exhaust gas is typically 5 to 10 percent. No data are available regarding grain loadings. Regulatory agencies consider that the dryers are in compliance.

Dryers 67, 68, and 69 are steam-heated units whose furnish is "mixed hardwoods," principally of southeastern species. Since the inlet temperatures are 300°F, no fine particles are generated by volatility of the wood. With steam heaters, no fine particles are formed by combustion of the energy source. Twenty percent of the exhaust gases from each of the three dryers is separated in a "skimmer," a centrifugal separator unit designed to remove large particles. This 20 percent portion of the exhaust gas stream is carried back to the dryer input. The remaining 80 percent is vented to the atmosphere. No grain loading data are available. Opacity is 0 percent, and the dryers are considered to be in compliance.

Table 7-3 presents summary data on partial-recirculation control systems.

Table 7-3. SUMMARY OF PARTIAL RECIRCULATION CONTROL SYSTEMS FOR PARTICLE DRYERS

Dryer No.[a]	Energy sources		Inlet temp., °F	Primary species	Exit conc., gr/sdcf	Opacity, %	Status
	Primary	Secondary					
49	Sanderdust	Natural gas	600-900	D. fir	0.18	10-20	Fails
50	Sanderdust	Natural gas	600-900	D. fir	0.09	10-20	Fails
59	Sanderdust	Boiler stack	800	Pine	Unknown	5-10	Complies
60	Sanderdust	Boiler stack	800	Pine	Unknown	5-10	Complies
67	Steam	Boiler stack	300	Hardwoods	Unknown	0	Complies
68	Steam	Boiler stack	300	Hardwoods	Unknown	0	Complies
69	Steam	Boiler stack	300	Hardwoods	Unknown	0	Complies

[a] Additional information on these dryers is given in Appendix D.

Success in Meeting Regulations

Two of the seven dryers equipped with partial-recirculation systems are borderline with respect to compliance. The combination of high-temperature drying of Douglas fir and firing of sanderdust generates significant amounts of fine particles, some of which are combustible. Even the combustible fraction has little opportunity to oxidize when recycled, because of low oxygen levels at the point of entry. For the other five dryers, which do not generate small particles, recycling works effectively to control large particles.

Problems With the Systems

From an operational standpoint the partial-recirculation systems present no apparent problems. They do conserve energy, as noted earlier.

Costs of Partial-Recirculation Systems

The only data available on costs of such systems are probably not at all representative of "normal" industrial applications. Dryers 59 and 60 required major revisions of the energy sources, the system piping, and numerous subsystems in addition to installation of the partial-recirculation subsystems. Total cost of revisions was estimated at $500,000 for each dryer.

For Dryers 49 and 50, the partial-recirculation subsystems were designed into the entire dryer system before construction. No information is available on the cost of the recirculation portion of the dryer system.

No data are available on costs for dryers 67, 68, and 69.

Recommended Applications of Partial-Recirculation Systems

Partial-recirculation systems cannot control fine particles effectively. They can be used very effectively for large particles when "skimmers" are used to concentrate the large particles in the recycled gas handling system. Therefore, these systems are recommended only for dryers in which fine particles are not generated either by the energy source or by the high-temperature evaporation of volatile organic components in the furnish. The chief benefit of partial recirculation is energy conservation.

MEDIUM- AND HIGH-ENERGY SECONDARY CYCLONE CONTROL DEVICES

Medium- to high-energy cyclone separators have been used on 9 of the 76 dryers evaluated in this study. These cyclones are provided in several air flow configurations, requiring use of one or two secondary fans as energy inputs to increase the collection efficiency. The cyclones are used as both primary and secondary collectors. Their use as primary collectors has met with limited success because of plugging. For purposes of this study, the cyclones are discussed in terms of use as secondary collectors. Exhaust gases from the primary cyclones are fed to these cyclones, which remove a portion of the remaining entrained particles from the gas stream.

Dryer 48 is a moderately low-temperature dryer (300 to 400°F inlet) drying Douglas fir from the 18 percent moisture level to the 5 percent level. It is sanderdust-fired and therefore generates fine particles as fly ash. Natural gas is used as auxiliary fuel. Rates of gas flow and material flow through the system are high (44,000 cfm and 40,000 to 50,000 lb/hr). As a result, significant amounts of large particles leave the primary cyclone in the exhaust gas stream. The secondary cyclone system works effectively to control these large particles (fibers). Emission levels are in the range of 0.06 gr/sdcf. Opacity, due principally to fine particles of fly ash from combustion of sanderdust, typically ranges from 10 to 15 percent.

Dryer 51 is very similar to Dryer 48. Although no exact data on inlet temperatures are available, they are expected to be moderately low, probably less than 400°F. The furnish is Douglas fir, and the moisture differential from inlet to exit is only 10 percent. Like Dryer 48 it is sanderdust-fired with natural gas backup. Large fibers are the primary problem in the primary cyclone exhaust, and the secondary cyclone controls these emissions effectively. Exit loading on the system is 0.05 gr/sdcf. Opacity, due again to fly ash-based fine particles in the sanderdust firing system, is typically 10 to 15 percent.

Dryer 53 is equipped with a cyclone as a secondary collector. In operation, the cyclone routinely plugged and interrupted operation of the plant. The dryer is now shut down completely. No emission data are available.

Dryer 54 is identical to Dryer 53 and is operating satisfactorily. The major difference in the two dryer systems is the furnish. Dryer 53 was set up to dry southern pine from 100 percent moisture to 22 percent (dry basis). The high moisture content of the exhaust gases undoubtedly acted to agglomerate the fines picked up in the secondary collector. Dryer 54 handles dry furnish only, typically drying from 22 percent moisture to 5 percent. No information is available concerning inlet temperatures to the dryer. At the temperatures used, however, the southern pine furnish presents no apparent difficulty by formation of fine particles due to volatile organic components. The energy source is primarily natural gas, with oil as auxiliary fuel.

The secondary cyclone handles large particles well. Exit grain loadings are 0.029 gr/sdcf. Opacity is 0 percent.

Dryers 57 and 58 are large, identical units equipped with medium-energy cyclones as secondary collectors. Both dryers are fired with natural gas, with propane as standby fuel. The furnish is "mixed hardwoods." Inlet temperatures are not known. No fine particles are formed, and opacity is 9 percent for the system. Fiber emissions are well controlled by the secondary cyclones. The grain loadings are 0.035 and 0.063 gr/sdcf, respectively from Dryers 57 and 58. Horsepower requirements of the secondary cyclones are high, 450 each. The gas flow rate through each system is 46,000 scfm.

Dryers 70, 71, and 72 are natural-gas-fired tube dryers handling mixed hardwoods. Since inlet temperatures are kept to 375°F, few if any fine particles are formed either by combustion or by evaporation of volatile components of the furnish. Opacity readings on the exhaust stacks are zero. Secondary cyclones were installed to control large-particle emissions from the systems. Grain loadings are about 0.05 gr/sdcf.

Table 7-4 presents summary data on the medium- and high-energy cyclone control systems.

Success in Meeting Regulations

Eight of the nine dryers equipped with secondary cyclones are operating within the emission limitations. (The ninth is shut down.) Dryers 48 and 51 are occasionally borderline with respect to opacity limits. Although cyclone systems are ineffective in controlling particles in the size range less than 10 microns, the secondary cyclones are performing well where large particles are the principle emission problem.

Table 7-4. SUMMARY OF MEDIUM AND HIGH-ENERGY SECONDARDY CYCLONE CONTROL DEVICES FOR PARTICLE DRYERS

Dryer No.[a]	Energy sources		Inlet temp., °F	Primary species	Exit conc., gr/sdcf	Opacity, %	Status
	Primary	Secondary					
48	Sanderdust	Natural gas	300-400	D. fir	0.06	10-15	Complies
51	Sanderdust	Natural gas	<400	D. fir	0.05	10-15	Complies
53				- NOT OPERABLE -			
54	Natural gas	Fuel oil	?	Pine	0.029	0	Complies
57	Natural gas	Propane	?	Hardwoods	0.035	0	Complies
58	Natural gas	Propane	?	Hardwoods	0.063	0	Complies
70	Natural gas	?	<375	Hardwoods	~0.05	0	Complies
71	Natural gas	?	<375	Hardwoods	~0.05	0	Complies
72	Natural gas	?	<375	Hardwoods	~0.05	0	Complies

[a] Additional information on these dryers is given in Appendix D.

Problems with the System

As noted earlier, secondary cyclones are prone to plugging in some circumstances. Very high moisture contents in the exhaust gases in combination with high concentrations of fiber particles may cause excessive plugging. Plant operators who have attempted to use these systems as primary cyclones have experienced some plugging difficulties.

The greatest limitation inherent in these systems is the high level of energy input required. Of the nine systems studied, power requirements ranged from 0.002 to 0.013 hp/cfm. The combined electricity bills for Dryers 57 and 58 (450 hp each) exceed $110,000 per year.

Cost of Medium-Energy Secondary Cyclone Control Systems

Cost data for installation of secondary control systems on Dryers 48, 51, 70, 71, and 72 show a range from $3.00 to $5.00/cfm. The other plant modificatons involved in retrofitting Dryers 57 and 58 raised the cost to $11.00/cfm. Accounting for inflationary factors, a reasonable range for installation costs today would be about $6/cfm, including engineering, materials, construction management, startup, and associated costs.

Recommended Applications of the Systems

Medium- and high-energy secondary cyclone control devices have proved successful in controlling large particles, in the size range above 10 microns. For dryers whose emissions include substantial quantities of small particles that result in the formation of visible blue haze, these systems are not adequate to control opacity.

MULTIPLE-CYCLONE CONTROL SYSTEMS

Success in Meeting Regulations

Only two dryers, 62 and 63, were equipped with multiple cyclones for secondary control systems. Both dryers are fired with fuel oil and have high inlet temperatures. Dryer 62 typically operates with inlet temperatures of 800 to 1000°F. Southern pine is the principal species of furnish. Apparently, organic material from the furnish collected in the multiple cyclone, and eventually a major fire occurred. The dryer is now shut down and is not expected to operate in the near future. The control device is beyond repair.

Dryer 63 operates with lower inlet temperatures (600 to 800°F). It is used to dry southern pine from the 20 percent to the 5 percent moisture level. The multiple-cyclone secondary collector works effectively to control large-particle emissions. The exit grain loading is 0.028 gr/sdcf. Although no information is available regarding opacity, the installation is said to be in compliance with regulations.

Problems with the Systems

Multiple cyclones may have a high energy requirement. For Dryer 63 the energy requirement per cfm is as high as that for the most demanding medium-energy secondary cyclone (0.013 hp/cfm), which amounts to 200 hp for the 15,000 cfm dryer.

Multiple cyclones may be subject to fires, as demonstrated by Dryer 62. With the exception of wet scrubber systems, however, all other secondary control devices have the same limitation. The difficulty is not so much the equipment design, but rather that the fibers collected in the systems are explosive and flammable.

Cost of Multiple-Cyclone Systems

Accurate cost information is not available for the two installations of multiple cyclones. A conservative estimate for complete installation including engineering, materials, construction management, installation, and startup is in the range of $4 to $6/cfm.

Recommended Applications of Multiple Cyclones

If judged on the basis of their use among the 76 dryers investigated, multiple cyclone control devices might not be recommended for dryer emission control purposes. They are useful in controlling particles of about 10 microns but are not recommended for control of fine particles that generate visible blue haze.

FABRIC-FILTER EMISSION CONTROL SYSTEMS

Success in Meeting Regulations

Of the 76 dryers investigated, only Dryer 44 is equipped with a fabric filter control device. This dryer is fired with natural gas, drying Douglas fir from the 50 percent moisture level to the 8 percent level. Inlet temperatures range from 385 to 550°F. Large-particle (fiber) emissions exceeded the allowable limits before the baghouse was installed, and the unit effectively controls the large-particle emissions.

At the higher emission temperature ranges, particularly with Douglas fir, opacity is a major concern. The fabric filter is not insulated and operates at approximately 175°F, somewhat below the expected condensation temperatures for most of the haze-forming organic materials. Surprisingly, condensation of these materials has not resulted in plugging or blinding of the filter cloth. Since the dryer is fired with natural gas, the energy source contributes no fine particles of fly ash. Blue haze can be seen leaving the bottom exit duct of the baghouse, but because the cross-sectional area of the exit duct is so large the system is subject to sufficient dilution from normal circulating air currents and therefore does not exceed the opacity limits of 20 percent.

Problems with the Fabric-Filter System

This system had operated only a few months at the time of evaluation for this study and has caused no unexpected problems or operational difficulties. Although there has been concern that condensation of the water vapor in the gas stream would tend to blind or plug the filter materials, this has not occurred. The short operational experience indicates that the fabric filter systems may provide a reasonable solution to control of particles.

Costs of the Fabric-Filter System

The installed cost of the system is $65,000 to handle 22,000 cfm, yielding a rate of about $3/cfm, which is a most competitive figure. Since this is a recent installation, the price should reflect current costs. The pressure drop across the baghouse is approximately 7 inches H_2O.

Recommended Applications of Fabric Filters

With limited operational experience on only one installation, there is little basis for endorsement of this approach to emission control of particle dryers. Fires and explosions have occurred on fabric filters used to control wood fiber emissions. These potential hazards should be considered.

Experience with fabric filters on other equipment indicates that they are very effective in controlling fiber emissions. With proper selection of the fabric, they can also be effective in controlling fly ash-type emissions such as those generated in combustion of wood-residue fuels. Observation of Dryer 44, however, indicates that the filters are not entirely effective in collecting volatile organic, haze-forming emissions. Thus, for high-temperature drying of Douglas fir, they are not necessarily an appropriate selection.

OTHER SYSTEMS FOR CONTROLLING DRYER EMISSIONS

Low-Temperature Operation

In review of the technology that has been applied to control emissions from dryers, emphasis to this point has been on tail-end control devices. Recognizing the importance of temperature in formation of small particles of organic matter, some companies have chosen to design and operate their dryers at temperatures below those at which haze is formed. In some instances this is accomplished by reducing the rate of flow of furnish to the dryers. In other cases, the same result can be achieved by drying very wet furnish in two stages rather than in a single step. Of the 76 dryers surveyed, 17 were not equipped with tail-end control devices but were maintained in compliance with opacity regulations by operating at low inlet temperatures (below 450°F). The dryers in this category are numbers 3, 21. 22, 24, 25, 30 through 39, 47, and 52. Dryers 3, 34, and 47 were fired with sanderdust, which provided an input of haze-forming fly ash. Opacity on these three dryers was estimated to be typically less than 10 percent, but emissions were visible. Opacity on the remaining 14 dryers was estimated to range from 0 to less than 10 percent.

Managers and operators agree that low-temperature operation is effective in meeting opacity requirements and also offers the advantage of minimizing fires. Offsetting these positive benefits is the additional capital cost required to permit this type of operation. Low feed rates of furnish to the dryer and/or staged drying both require more drying equipment than is needed for high feed rates to single-stage dryers. If low feed rates are used without additional equipment, production is reduced. In the highly competitive board and panel markets, reduced production could affect competition cost operations.

The maximum temperature on the inlet to the dryer is not easily specified, since formation of blue haze is very species-dependent. Many plants use mixed species in their furnish, and the upper limit for one species may not be the same as that for another. The situation is further complicated by lack of knowledge about the volatile organic content of selected species and their temperature-dependence. Experience with Douglas fir suggests that if the maximum inlet temperature is below 450°F, blue haze formation will be within current opacity restrictions. This is purely a rule of thumb, however, which does not take into account the fuel used, type of dryer, particle size, and other factors that affect opacity. With southern pine, inlet temperatures might go as high as 600°F without appreciable haze formation, as demonstrated by Dryer 61, which has no tail-end control device, is fired with sanderdust, and is considered to operate at 0 percent opacity.

Energy use for low-temperature drying is about the same as for higher temperatures on the basis of Btu per pound of water evaporated (see Figure A-2, Appendix A). If high inlet temperatures result in the need for energy-consuming tail-end control systems to reduce opacity, the overall energy use may be significantly greater than in lower-temperatures operation. Energy balances should be considered in evaluating alternative approaches to opacity control.

The alternative of reducing drying temperatures to meet emission regulations entails a space requirement for addition of more dryers. Since particle and fiber dryers are fairly large installations, many plants may not be able to provide enough space for additional dryers.

Installation of 'Short Fall Fill'

Of the 76 dryers considered in this report, 2 were designed with single-pass rotating dryer drums. This drum design has been retrofit with internal steel structures called 'short fall fill' at two plants in the U.S.[11] (Neither plant was visited during this study.) 'Short fall fill' is a descriptive term meaning that internal baffles have been placed in such a fashion that the particles passing through the dryer can 'fall' only a short distance before coming into contact with a baffle. T[illegible]irect contact of the particles with the baffles assists in drying the particles, in part through conductive heat transfer and in part through the greater turbulence around each particle as it comes into contact with and then separates from the internal baffles. For those dryers that have been so modified, the initial production rates have been maintained while the inlet temperatures were reduced and blue haze was eliminated in operation at design capacities.

No cost data are available concerning installation of short fall fill. It is, however, designed only for use on single-pass rotating dryer drums. As noted in Appendix A, the vast majority of plants are using triple-pass rotary dryers, for which installation of this baffle system would not be appropriate. Patents on this system are held by Stearns-Rogers Co. of Denver.

SAFETY CONSIDERATIONS RELATIVE TO DRYER EMISSION CONTROL DEVICES

Manufacturers of wood-based particle and fiber panel products are highly safety conscious. The handling of small, dry wood particles makes these manufacturing facilities prone to fires and occasional major explosions. On

March 23, 1976, a major fire destroyed a northern California plant. Six men were killed in the holocaust.

The potential for fires and explosions, particularly in and around dryer systems, is of significant concern to plant owners and operators. Their concern has increased as the complexities of the operations have expanded to include dryer emission control. Consideration must be given to these potential hazards in the design, installation, and operation of control devices.

Wet scrubbers present few hazards. Because they involve water sprays and designs to trap the small fibers in water, fire is not a problem. Full-recirculation systems, however, present a serious potential hazard. They are typically operated with high inlet temperatures that drive off volatile, combustible, organic materials from the wood furnish. As these are recirculated to the high-temperature combustion unit, they are burned along with any fibers that were not collected by the primary cyclone. The high temperatures at the dryer inlet could easily set the furnish on fire, except that the combustion products are low in oxygen. The low oxygen concentration prevents rapid oxidation of the dryer furnish. If an inspection port is left open or is opened during operation, however, the oxygen concentration could increase enough to result in a major fire. Partial recirculation control systems are subject to the same hazards.

Secondary cyclones are not without fire and explosion potential. In some units installed in the southeastern U.S., condensation of the volatile organic materials on interior surfaces has built up a layer of combustible materials several inches thick. A serious fire that destroyed a unit emphasizes the need for proper design and operation of these systems.

As noted earlier, Dryer 62 is not functional. A fire destroyed the dryer and the multiclone collector, which had accumulated significant quantities of combustible, condensed organic materials in the interior.

Of all the control devices, fabric filters are most feared for their fire and explosion potential. These filters may collect explosive concentrations of combustible wood fibers. One northwestern plant finally removed a baghouse installed on a particle transfer system after the fifth fire in the system destroyed the bags.

Decisions concerning installation of any type of emission control equipment in a wood-based particle or fiber manufacturing plant, must be based on consideration of the safety aspects of the alternative devices. Particular attention should be given to "upset" conditions, plugging of primary cyclones, variations in material flow rates, and other process variables that could result in extreme hazards.

8. INDUSTRY-WIDE COMPLIANCE STATUS SUMMARY

Information was compiled and developed to ascertain the compliance status and compliance schedules for wood particle dryers operated in each plant in the U.S. manufacturing particleboard, medium-density fiberboard, and hardboard. Source data reports from CDS and NEDS were accessed for the requisite data. For most regions, detailed compliance information within these data systems was limited, incomplete, and/or unknown. The information sought included number of dryers operated, dryer compliance status, and dates of scheduled incremental actions in accordance with a State Implementation Plan (SIP). Directories of the Forest Products Industry, the National Particleboard Association, and the Acoustical and Board Products Association were used to verify the list of board producers and to provide production data. All EPA regional offices were contacted for supportive information, as were several local control agencies having particle dryers under their jurisdiction. It was beyond the scope of this task to contact individual plants or all local control agencies to obtain detailed supportive or missing data.

The data were assembled and tabulated by firm for the following categories:

- Number of dryers.
- Facility identifications (state, county, CDS number, NEDS number, state registration number).
- Dates of SIP incremental scheduled actions.
- General compliance status and method of determination.

Seventy-five plants were identified under Standard Industrial Classifications (SIC's) 2492 and 2499 as manufacturers of particleboard or medium-density fiberboard. Of these, 35 demonstrated full dryer compliance and/or entire source compliance (which indicates complete individual point compliance). It was not possible in all cases to identify the exact number of dryers operated by each plant or specific compliance status, since these data were missing in some of the CDS sumamries. The dates of SIP scheduled incremental actions were recorded where available. Table 8-1 tabulates the aforementioned for each identified plant alphabetically by state. A listing of each plant with its address, numerically arranged to correspond with the listing in Table 8-1, is included in Appendix E.

Table 8-2 presents, in the same format as Table 8-1, the data for all verified hardboard manufacturing plants in the United States, a total of 20. All plants were identified under SIC's 2490 and 2499. Of the 20 plants, 13 demonstrated full dryer compliance and/or entire source compliance (indicating complete individual point compliance). As with the particleboard plants, it was not always possible to identify the number of dryers operated by each plant or to obtain complete compliance schedules. A listing of each plant with its address, numerically arranged to correspond with the listing in Table 8-2, is presented in Appendix F.

Table 8-3 lists plants that probably include particleboard or hardboard operations but could not be verified, either through one of the wood products industry directories or through the CDS or NEDS data summaries. The corresponding list of addresses is presented in Appendix G, alphabetically by plant, arranged sequentially by state.

Table 8-1. COMPLIANCE STATUS SUMMARY: PARTICLEBOARD AND MEDIUM-DENSITY FIBERBOARD PLANTS

Facility	No. dryers	Facility identification					SIP schedule					Dryer Compliance		
									Final compliance			Status		Eval. method
		State	County	CDS #	NEDS X ref	State reg. #	Type	Submit plan	Sched	Achiev	Status	In	Out	
1. Giles & Kendall[d]		01												
2. Louisiana Pacific[a,b]		01	0280	00014	0014		none					x		
3. Louisiana Pacific[d]		01		production to start 6/76										
4. MacMillan Bloedel Particleboard[a,b,d]		01	3460	00004								x		
5. Olinkraft[a,b,d]		01	2420	00004	0004		none						Unknown[f]	
6. Southwest Forest Industries[a,d]		03	0200	00400								x[e]		insp
7. Georgia Pacific[a,b,d]		04	0080	00002	0010								x	
8. International Paper[a,b,d]		04	1160	00005	0005		none					x	unknown[f]	
9. Singer[c,d,e]		04										x		
10. Wynnewood Products		04	1100	00001	0001		pend					x		
11. American Forest Products[b,d]	2	05	0220	00005	0001		appr	3/14/74	3/24/75		unknown[f]	x		on sched
12. Big Bear Board Products[b,d]		05	6700	00035									unknown[f]	
13. Champion International[b,d]		05	7580	00002								x[e]		insp
14. Collins Pine[b,d]		05	6020	00003								x[e]		insp
15. Fiberboard[d]		05		production started 1975										
16. Georgia Pacific[a,d]		05	4540	00013	0045				6/74		variance		x	on sched
17. Hambro Forest Products[a,d]	1	05	2000	00002	0005		none	2/28/74		2/19/75	achieved	x		insp

Data source: [a] CDS Source Data Summary, CDS "quick look," or NEDS

[b] EPA Regional Office

[c] Local Control Agency

[d] Listed in at least one directory: Forest Products Industry, Acoustical & Board Products Association, National Particleboard Association

[e] Compliance status of entire source

[f] Where data is indicated as "unknown," it was listed as such in CDS and/or NEDS summaries

Table 8-1 (continued). COMPLIANCE STATUS SUMMARY: PARTICLEBOARD AND MEDIUM-DENSITY FIBERBOARD PLANTS

Facility	No. dryers	Facility identification					SIP schedule					Dryer Compliance		
								Submit plan	Final compliance			Status		Eval. method
		State	County	CDS #	NEDS X ref	State reg. #	Type		Sched	Achiev	Status	In	Out	
18. Humboldt Flakeboard[a,d]	1	05	3300	00522	0047		none					x		NEDS
19. Louisiana Pacific[d]		05												
20. Sequoia Board[a]	2	05	4320	00010	0017		none						x	insp
21. Georgia Pacific[d]		11												
22. Temple Industries[d]		11												
23. Weyerhaeuser[a,d]	1	11	1340	00001	0001		Enf/ Adm					x[e]		cert
24. Potlatch Forest[a,d]		13	0860	00010			pend					x[c]		
25. Swain Industries[d]		15												
26. Tenn-Flake[a,d]		18	0200	01405		OT-73-14	appr		4/1/74		unknown[f]		x	off sched
27. Duraflake South[a,d]	1	19	1720	00004	0004		none						unknown[f]	
28. Louisiana Pacific[a,d]		19	1680	00001	0001		none					x[c]		cert
29. Olinkraft-Particle[a,d]	1	19	2920	00003	0003		none						x	cert
30. Champion International[d]		23												
31. Blandin Wood Products[b,d]		24	1660	00001	0001							x[e]		cert
32. Cladwood[d]		24												
33. Champion International[d]		25												
34. Georgia Pacific[a,d]		25	2980	00004	0004		appr						x[e]	off sched

Data source: [a] CDS Source Data Summary, CDS "quick look," or NEDS

[b] EPA Regional Office

[c] Local Control Agency

[d] Listed in at least one directory: Forest Products Industry, Acoustical & Board Products Association, National Particleboard Association

[e] Compliance status of entire source

[f] Where data is indicated as "unknown," it was listed as such in CDS and/or NEDS summaries

Table 8-1 (continued). COMPLIANCE STATUS SUMMARY: PARTICLEBOARD AND MEDIUM-DENSITY FIBERBOARD PLANTS

Facility	No. dryers	Facility identification					SIP schedule					Dryer Compliance		
									Final compliance			Status		Eval. method
		State	County	CDS #	NEDS X ref	State reg. #	Type	Submit plan	Sched	Achiev	Status	In	Out	
35. Georgia Pacific[a,d]		25	2500	00002									x[e]	off sched
36. Kroehler Manufacturing[a,d]		25	1460	00031									x[e]	off sched
37. Evans Products[a,d]	4	27	1100	00002	0002		un-known[f]						x[e]	on sched
38. Plum Creek Lumber[a,d]		27	0480	10002								x[e]		cert
39. Ponderosa Products[a,d]		32	0140	00902									unknown[f]	
40. Carolina Forest Products[d]		34												
41. Evans Products[a,d]	3	34	0720	09001	0020		un-known[f]		12/74		variance		x	
42. Georgia Pacific[a,d]		34	0880	00050									x[e]	off sched
43. International Paper[a,d]		34	3180	00007	0007		un-known[f]		5/73		variance		x	
44. Nu-Woods[d]		34												
45. Permaneer[d]		34												
46. Surecore[c,d]		37	2280	00001			none					x[e]		no sched
47. Weyerhaeuser[a,d]	3	37	1760	00002	0002		none						x[e]	cert
48. Bohemia[a,d]	2	38	1020	00051	0529	20-0529	Enf ord		6/30/76	12/9/5	achieved		x	on sched

Data source: [a] CDS Source Data Summary, CDS "quick look," or NEDS
[b] EPA Regional Office
[c] Local Control Agency
[d] Listed in at least one directory: Forest Products Industry, Acoustical & Board Products Association, National Particleboard Association
[e] Compliance status of entire source
[f] Where data is indicated as "unknown," it was listed as such in CDS and/or NEDS summaries

Table 8-1 (continued). COMPLIANCE STATUS SUMMARY: PARTICLEBOARD AND MEDIUM-DENSITY FIBERBOARD PLANTS

Facility	No. dryers	Facility identification					SIP schedule					Dryer Compliance		
									Final compliance			Status		
		State	County	CDS #	NEDS X ref	State reg. #	Type	Submit plan	Sched	Achiev	Status	In	Out	Eval. method
49. Boise Cascade[a,d]	4	38	1800	00003	0002	31-0002	pend		6/30/75	6/1/75	achieved	x		cert
50. Brooks-Willamette[a,d]	3	38	0500	00004	0002	09-0002	pend		11/1/74	2/1/75	achieved	x		S.test
51. Publishers' Paper[d]		38										x		
52. Duraflake[a,d]	6	38	1080	00014	0143	22-0143	Enf ord	1/15/75	7/31/75		violation		x	off sched
53. Fiberboard[a,d]		38	0880	00001								x[e]		
54. Medford[a,d]	2	38	0840	00011					12/76		on sched		x	
55. Permaneer[a,d]	1	38	0520	00034	0013	10-0013	none	7/1/75	9/30/79		on sched		x	
56. Permaneer[a,d]	2	38	0840	10009	0027	15-0027	← Not in operation →							
57. Roseburg Lumber[a,d]	10	38	0520	00030	0063	10-0063	pend	-3/75	11/1/75	9/75	achieved	x		insp
58. Timber Products[a,d]		38	0840	00019	0032	15-0032	pend		12/31/73	12/31/73	ach'vd	x		cert
59. Weyerhaeuser[a,d]	6	38	0920	00008	0034	18-0034	pend			6/12/75	achieved	x		cert
60. Weyerhaeuser[a,d]	11	38	1020	00023	8866	20-8866/67/68							x	S. test
61. Georgia Pacific[a,d]		42	0420	00005								x[e]		cert
62. Georgia Pacific[a,d]		42	0680	00003								x[e]		cert
63. Holly Hill Lumber[a,d]		42	1860	00002								x[e]		cert

Data source: [a] CDS Source Data Summary, CDS "quick look," or NEDS
[b] EPA Regional Office
[c] Local Control Agency
[d] Listed in at least one directory: Forest Products Industry, Acoustical & Board Products Association, National Particleboard Association
[e] Compliance status of entire source

Table 8-1 (continued). COMPLIANCE STATUS SUMMARY: PARTICLEBOARD AND MEDIUM-DENSITY FIBERBOARD PLANTS

Facility	No. dryers	Facility identification					SIP schedule					Dryer Compliance		
									Final compliance			Status		
		State	County	CDS #	NEDS X ref	State reg. #	Type	Submit plan	Sched	Achiev	Status	In	Out	Eval. method
64 International Paper[a,d]		42	1140	00002								x[e]		cert
65. Tenn-Flake[a,d]		44	1260	00021	0021	32-0021	none					x[e]		cert
66. Kirby Lumber[c,d]	1	45	2310	00002	0002	107-625-6				12/31/73	ach'vd "A"	x	x	insp
67. Louisiana Pacific[a,d]	1	45				111-292-9				12/31/73	ach'vd "A"	x		insp
68. Permaneer[c,d]	1	45	0870	00011	0003	115-229-7				12/31/73	ach'vd "A"	x		insp
69. Temple Industries[c,d]	1	45	0110	00002	0002	104-0003-1							x	insp
70. Champion International[a,d]		48	1420	00002										insp
71. Masonite[a,d]		48	3120	00001	0001								x[e]	on sched
72. Union Camp[a,d]		48	2940	00004									x[e]	on sched
73. International Paper[a,d]	1	49	0480	00013	0013	SWAPCA 73-7	Enf ord	6/1/71	6/1/72	8/6/74	ach'vd	x		cert
74. Rodman Industries[a,d]	1	51	1960	00008	0003	380006							x[e]	on sched
75. Weyerhaeuser[a,d]	1	51	4060	00004	0003								x	on sched

Data source: [a] CDS Source Data Summary, CDS "quick look," or NEDS
[b] EPA Regional Office
[c] Local Control Agency
[d] Listed in at least one directory: Forest Products Industry, Acoustical & Board Products Association, National Particleboard Association
[e] Compliance status of entire source
[f] Where data is indicated as "unknown," it was listed as such in CDS and/or NEDS summaries

Table 8-2. COMPLIANCE STATUS SUMMARY: HARDBOARD PLANTS

Facility	No. dryers	Facility identification					SIP schedule					Dryer Compliance		
									Final compliance			Status		
		State	County	CDS #	NEDS X ref	State reg. #	Type	Submit plan	Sched	Achiev	Status	In	Out	Eval. method
1. Chicago Hardboard		14											unknown[f]	
2. Abitibi[b,d]		23	0220	00002		B-1476						x[e]		cert
3. Boise Cascade[b,d]		24	1780	00001	0001								x[e]	
4. Superwood[a,d]		24	0240	00001	0004							x[e]		cert
5. Superwood[a,b,d]		24	3260	00031	0031								x[e]	on sched
6. Celotex[b,d]	3	33	1520	00001		123000 -0017	Enf/ Adm	11/1/74	3/30/75	8/75	achieved	x		cert
7. Georgia Pacific[a,d]		34	2940	00041	0041		Enf/ Adm						x[e]	off sched
8. Masonite[a,d]		34	2840	00039	0039		Enf/ Adm					x[e]		cert
9. Weyerhaeuser[a,d]		34	0720	00020								x[e]		cert
10. Georgia Pacific[a,d]	7	38	0320	00007	0011	06-0011	none			11/19/5	achieved	x		insp
11. Pope & Talbot[a,d]	4	38	1020	00049	6403	20-6403 /01/04	none			12/9/75	achieved	x		cert
12. U.S. Plywood[a,d]	1	38	1080	00016	5195	22-5195	pend	12/31/3	12/31/5		resched		x	off sched
13. Weyerhaeuser[a,d]	4	38	0920	00011	0035	18-0035	pend			6/12/75	achieved	x[e]		cert
14. Masonite[a,d]		39	1000	00009								x[e]		cert
15. Celotex Sellers[a,b,d]		42	1660	00006			none					x[c]		
16. Champion International[a,d]		42	2440	00026								x[e]		cert

Data source: [a] CDS Source Data Summary, CDS "quick look," or NEDS
[b] EPA Regional Office
[c] Local Control Agency
[d] Listed in at least one directory: Forest Products Industry, Acoustical & Board Products Association, National Particleboard Association
[e] Compliance status of entire source
[f] Where data is indicated as "unknown," it was listed as such in CDS and/or NEDS summaries

Table 8-2 (continued). COMPLIANCE STATUS SUMMARY: HARDBOARD PLANTS

Facility	No. dryers	Facility identification					SIP schedule					Dryer Compliance		
									Final compliance			Status		
		State	County	CDS #	NEDS X ref	State reg. #	Type[c]	Submit plan	Sched	Achiev	Status	In	Out	Eval. method
17. Celotex[a,d]		44	1460	00008	0008								x	off sched
18. Temple Industries[d]		45												
19. Evans Products[a,d]		48	1460	00002	0003				6/75			x[e]		cert
20. Evans Products[b,d]		51	2860	00003	0003	510003						x[e]		cert

Data source: [a] CDS Source Data Summary, CDS "quick look," or NEDS
[b] EPA Regional Office
[c] Local Control Agency
[d] Listed in at least one directory: Forest Products Industry, Acoustical & Board Products Association, National Particleboard Association
[e] Compliance status of entire source

Table 8-3. PLANTS IN QUESTIONABLE STATUS

(Exact Product Unverified)

Facility	Facility identification					SIP schedule					Dryer Compliance		
								Final compliance			Status		Eval. method
	State	County	CDS #	NEDS X ref	State reg. #	Type	Submit plan	Sched	Achiev	Status	In	Out	
1. American Forest Products[a]	05	5940	00505	0013		none					x[c]		insp
2. Fiberite West Coast[a]	05	5440	00002	0009		appr					x[c]		insp
3. Georgia Pacific[a,e]	05	4540	00513	0033		none						x[e]	
4. Louisiana Pacific[a,d]	05	0960	00006								x[c]		insp
5. U.S. Plywood[a]	05	7580	00002								x[e]		insp
6. Pack River[a]	13	0240	00007			none					x[c]		cert
7. Georgia Pacific[a]	18											unknown[e]	
8. International Paper[a]	25	2540	00003	0003								x[e]	off sched
9. Georgia Pacific[a]	34	1940	00047	0047		Enf/ Adm					x[e]		cert
10. Georgia Pacific[a]	34		00040									x[e]	
11. Georgia Pacific	34		00030								x		cert
12. Masonite[a]	34	1060	00130	0130	T-2329	none						x[c]	

Data source: [a] CDS Source Data Summary, CDS "quick look," or NEDS
[b] EPA Regional Office
[c] Local Control Agency
[d] Listed in at least one directory: Forest Products Industry, Acoustical & Board Products Association, National Particleboard Association
[e] Compliance status of entire source

Figure 8-1 shows the distribution of all verified plants summarized in Tables 8-1 and 8-2 (total 95) by state. The greatest concentration (approximately 29 percent) occurs in Oregon and California; the Region IV (southeastern) states account for an additional 32 percent.

In summary, the data from the individual plant surveys and the compliance status survey both indicate an industry-wide average of about three or four wood particle dryers per plant. Of the 95 particleboard and hardboard plants verified, about 47 percent had dryers in compliance, 25 percent were not in compliance, and no data were available to determine the status of the remaining 27 percent. Twelve plants were identified that could not be verified as either particleboard or hardboard producers. No data are available to indicate the average period of time required for dryers to achieve full compliance from the original scheduled date of control plan submission.

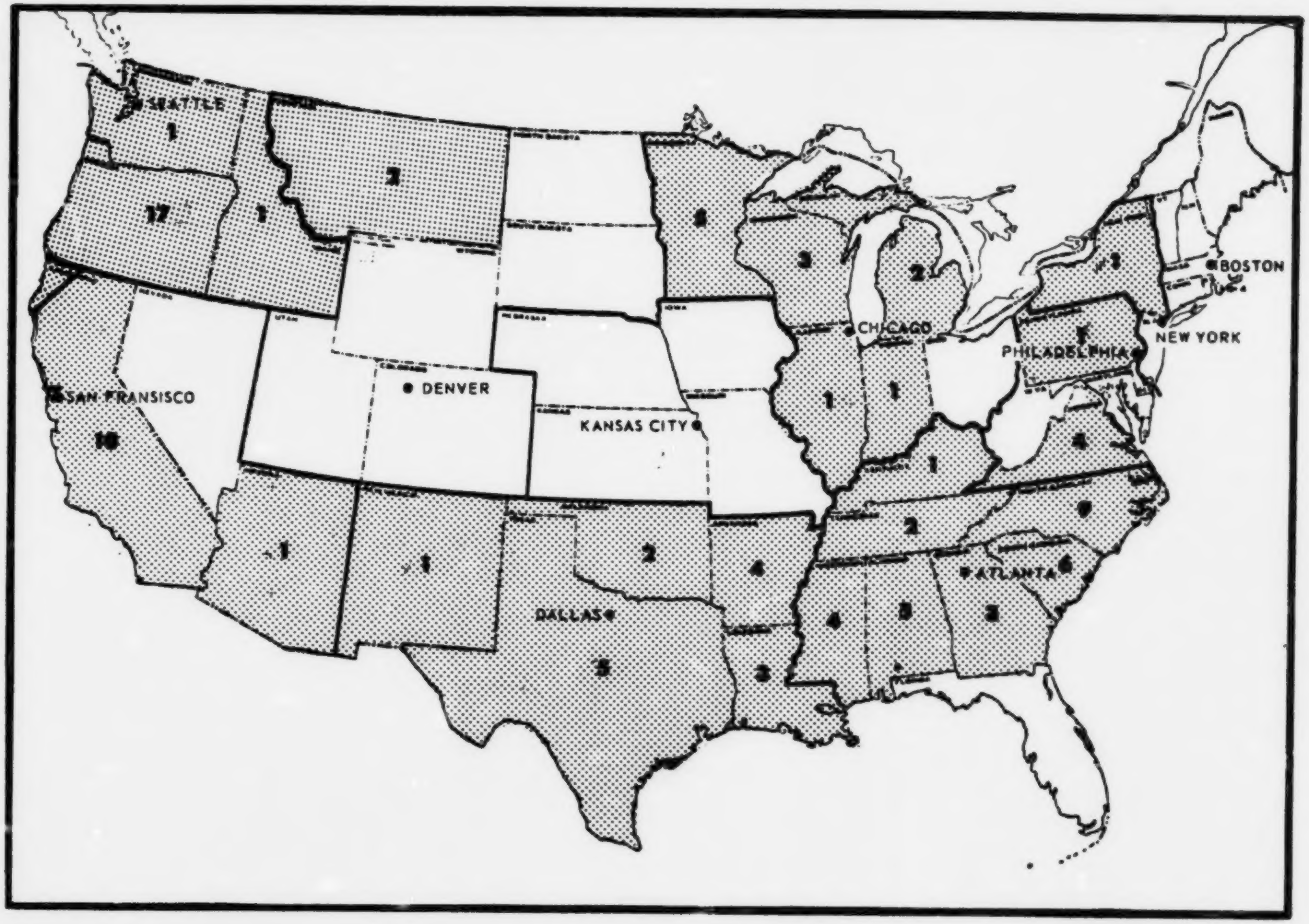
SEATTLE
1
17
1
2
SAN FRANSISCO
10
DENVER
KANSAS CITY
1
1
DALLAS
5
2
4
3
3
2
CHICAGO
1
1
1
2
4
3
3
PHILADELPHIA
NEW YORK
BOSTON
4
7
6
ATLANTA

Figure 8-1. Distribution of particleboard and hardboard plants in the United States (number of verified plants per state).

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13. Rules and Regulations Governing the Control of Air Pollution. State of North Carolina, Dept. of Natural and Economic Resources, Office of Water and Air Resources.

APPENDIX A

INTRODUCTORY NOTES ON THE THEORY OF PARTICLE DRYING

INTRODUCTORY NOTES ON THE THEORY OF PARTICLE DRYING

In the manufacturing of wood-based fiber and particle panel products, control of the moisture content of the raw materials is critical. Moisture affects the quality of the finished products and the bonding abilities of the resins. Moisture can create special problems in the hot presses as it expands in the vapor state and causes "blows". Raw materials for the manufacture of panel products are received with a wide range of moisture contents. Table A-1 indicates typical moisture contents for "green" material of some north American species.[4] Note, that moisture levels vary widely among species and within species. In most softwoods the moisture content of the sapwood is typically much higher than that of the heartwood. Since smaller trees have a much larger percentage of sapwood than heartwood, they tend to have high moisture levels. Moisture content of old, large trees is therefore lower than that of small young trees.

Moisture content of particle furnish for panel products may be different from the values in Table A-1 because of these variations. It may vary also with the manufacturing operations that generate the furnish. Planer shavings, for example, may be predried in a kiln, whereas sawdust may be wetted by the water added from sawguides.

Furnish for particle products is dried by raising the temperature of the wood to a level high enough to evaporate the undesirable moisture fraction. When a wet solid undergoes thermal drying, two processes occur simultaneously:

Table A-1. DENSITY AND MOISTURE CONTENT OF SOME TYPICAL NORTH AMERICAN WOOD SPECIES[4]

Species	Green[a] moisture content, % H_2O by wt. (dry basis)	Water per Unit Vol, lb/ft^3
Softwoods		
Douglas fir		
Old growth	45	12.6
Second growth	60	16.8
Englemann Spruce	60	12.0
Ponderosa Pine	100	23.7
Southern Yellow Pine	100	29.3
Western Hemlock	100	23.7
Hardwoods		
Northern Red Oak	80	27.9
Red Alder	100	23.1
Yellow Birth	75	25.7
Yellow Poplar	90	22.5

[a] Green moisture content refers to the moisture content of fresh cut wood samples.

1. Heat Transfer - Transfer of heat energy to the wet solid to raise the temperature high enough for evaporation to take place;
2. Mass Transfer - Transfer of the moisture contained in the interior of the wood to its surface, from which the moisture evaporates.[10]

Heat energy transfer in a drying process can occur by convection, radiation, conduction, or any combination of these. Mass transfer of moisture from the solid to the gaseous environment is dependent on the internal movement of moisture from the interior to the surface, and the diffusion of evolved water vapor away from the surface. Either of these two factors may be limiting in the drying process. The internal movement of moisture is a function of physical characteristics of the solid and its moisture content; removal of water vapor from the surface depends on external conditions such as temperature, humidity, flow rate of the surrounding air, and area of exposed solid surface.

In a particle dryer, the energy requirements are related to five factors:

1. Heat energy imparted to raise the temperature of the wood and the water.
2. Heat energy required to vaporize the water.
3. Loss of heat energy by venting or exhausting of the gas stream to atmosphere.
4. Loss of heat energy by radiation and convection from the dryer.
5. Loss by other mechanisms such as leaks, faulty steam traps, etc.

A significant amount of drying energy (ΔH_s) is expended in raising the temperature of the wood and water from ambient to the evaporation temperature. Assuming that all other energy losses could be eliminated, the minimum energy requirement for evaporation drying would be:[4]

$$\Delta H_{min} = \Delta H_v + \Delta H_s \qquad (1)$$

Expressed in terms of Btu/lb of water evaporated:

$$\Delta H_v \doteq 1000 \text{ Btu/lb} \qquad (2)$$

$$\Delta H_s = \frac{\left[C_{wd} + \left(\frac{M_i}{100} \times C_{wa}\right)\right] \Delta T}{\left[\frac{M_i - M_f}{100}\right]} \qquad (3)$$

where:

C_{wd} = specific heat of wood (0.3 Btu/lb°F)

C_{wa} = specific heat of water (1.0 Btu/lb°F)

M_i = initial moisture content (%), dry basis

M_f = final moisture content (%), dry basis

ΔT = temperature change from ambient to evaporation temperature (°F)

From the above, Eq. 1 easily reduces to:

$$\Delta T_{min} = 1000 + \frac{[30 + M_i]}{[M_i - M_f]} \Delta T \qquad (4)$$

ΔT_s is shown in Figure A-1 for a range of initial moisture contents, final moisture contents, and temperature increases. It is clear that this value for drying energy becomes quite high, particularly with low initital moisture contents and large temperature increases. This energy added to ΔH_v gives the minimum energy required exclusive of venting and other dryer losses. This can range from 1100 Btu/lb to more than 1500 Btu/lb (See equations 1 & 2).

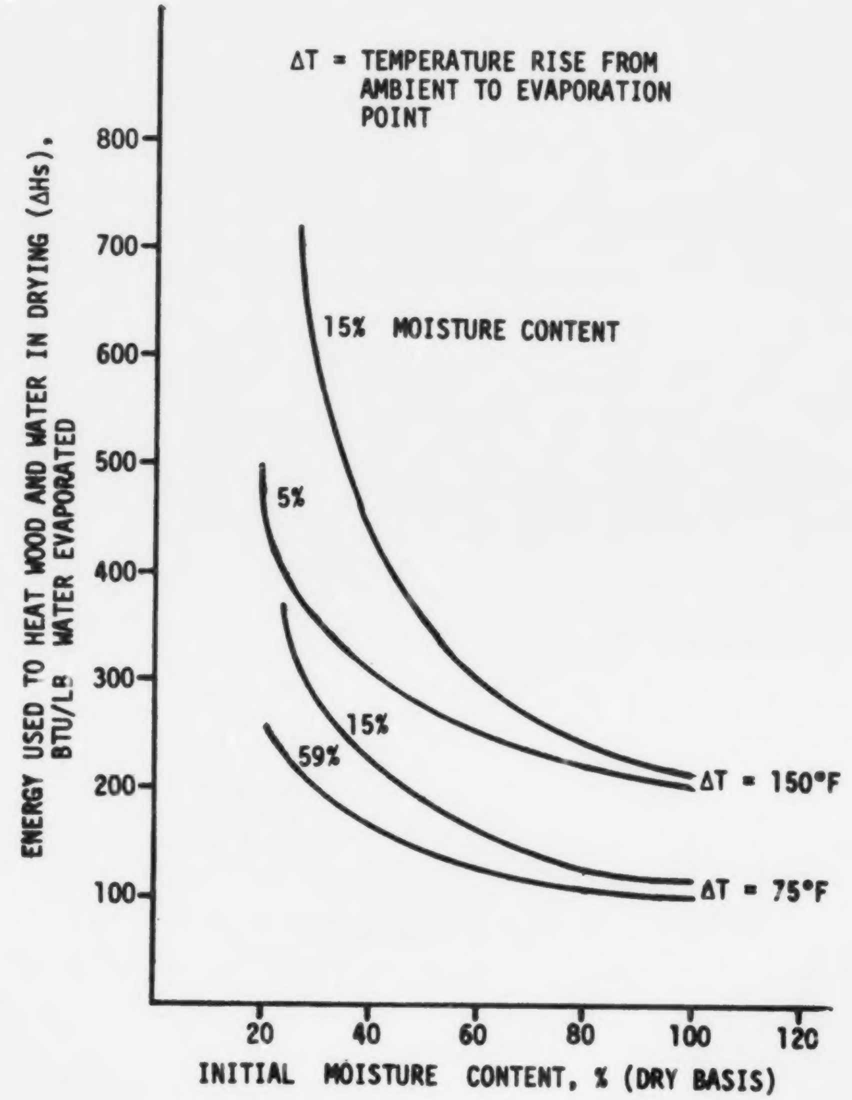


Figure A-1. Sensible heat imparted to wood and water to raise it to the evaporation temperature.

The energy required to convert water from the liquid to the gaseous phase is called the heat of vaporization. For wood at initial moisture contents above 30 percent the "heat of wetting" becomes a significant part of the total energy and must be added to the heat of vaporization. This is illustrated in Figure A-2. In most drying processes, the heat of wetting can be ignored. Heat of vaporization varies only slightly in the range of normal drying temperatures from 1037 Btu/lb at 100°F to 970 Btu/lb at 212°F.

Venting or exhausting of air from a dryer represents another major source of energy loss. As a rough approximation, energy use in drying is proportional to the temperature drop in the air as it passes through the dryer.[4]

$$\Delta H_{min} \ \alpha \ (T_E - T_L) \qquad (5)$$

where

T_E = Temperature entering

T_L = Temperature leaving

Energy loss in venting is proportional to the difference between ambient air temperature T_A and vented air, usually T_L and the fraction of vented air X_v:[4]

$$\Delta H_v \ \alpha \ (T_L - T_A) \ (X_v)$$

The ratio of vented energy to minimum drying energy is:

$$\frac{\Delta H_v}{\Delta H_{min}} = \frac{(T_L - T_A) \ (X_v)}{(T_E - T_L)}$$

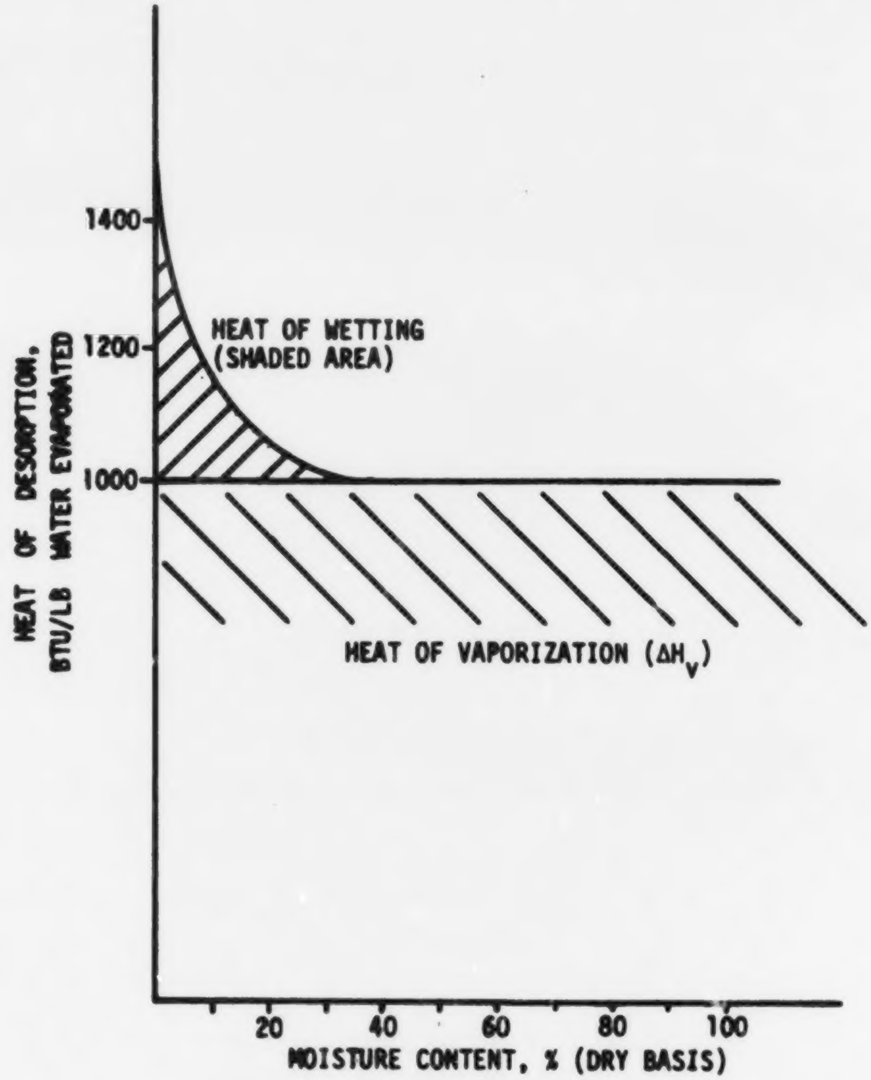


Figure A-2. Energy required to evaporate water from wood as a function of moisture content.

Vented energy may amount to less than 10 percent of total energy in dryers where the proportion of air vented is small or the temperature of vented air is near ambient. It may be well over 50 percent of the total energy in some nonrecirculating particle dryers. Figure A-3 shows the amount of energy lost through venting in a nonreciculating dryer from which all the air is exhausted to the atmosphere. As entering air temperature goes up and exhaust temperature goes down, the amount of energy lost through venting decreases. The loss through venting is reduced in direct proportion to the amount of air recycled through the dryer.

Adding the amount of heat lost through venting to ΔH_{min} provides a fair approximation of the minimum drying energy requirement. It typically ranges from 130 Btu/lb of water evaporated to as much as 3000 Btu/lb. Actual drying energy will be somewhat above these values because of other energy losses, dryer design, or maintenance deficiencies.

Particles, including wood chips, planer shavings, sawdust, and flakes are normally dried on a continuous basis in rotary drum dryers. Fibers, because of the low bulk density, are normally dried in a tube dryer with significantly higher volumes of air and somewhat lower inlet temperatures. Most particle and fiber dryers are single-pass in the sense that the air is exhausted after passing through the dryer. Because of this, thermal efficiency is highly sensitive to the entering and exhaust air temperatures and the ambient air conditions as indicated above. As a general rule, drum dryers require 1500 to 1900 Btu/lb of water evaporated for wet material (starting at 100 percent moisture content on a dry basis) and 1900 to 2300 Btu/lb of water evaporated for particles in the 20 to 30 percent moisture range.[4] Tube dryers are somewhat less efficient

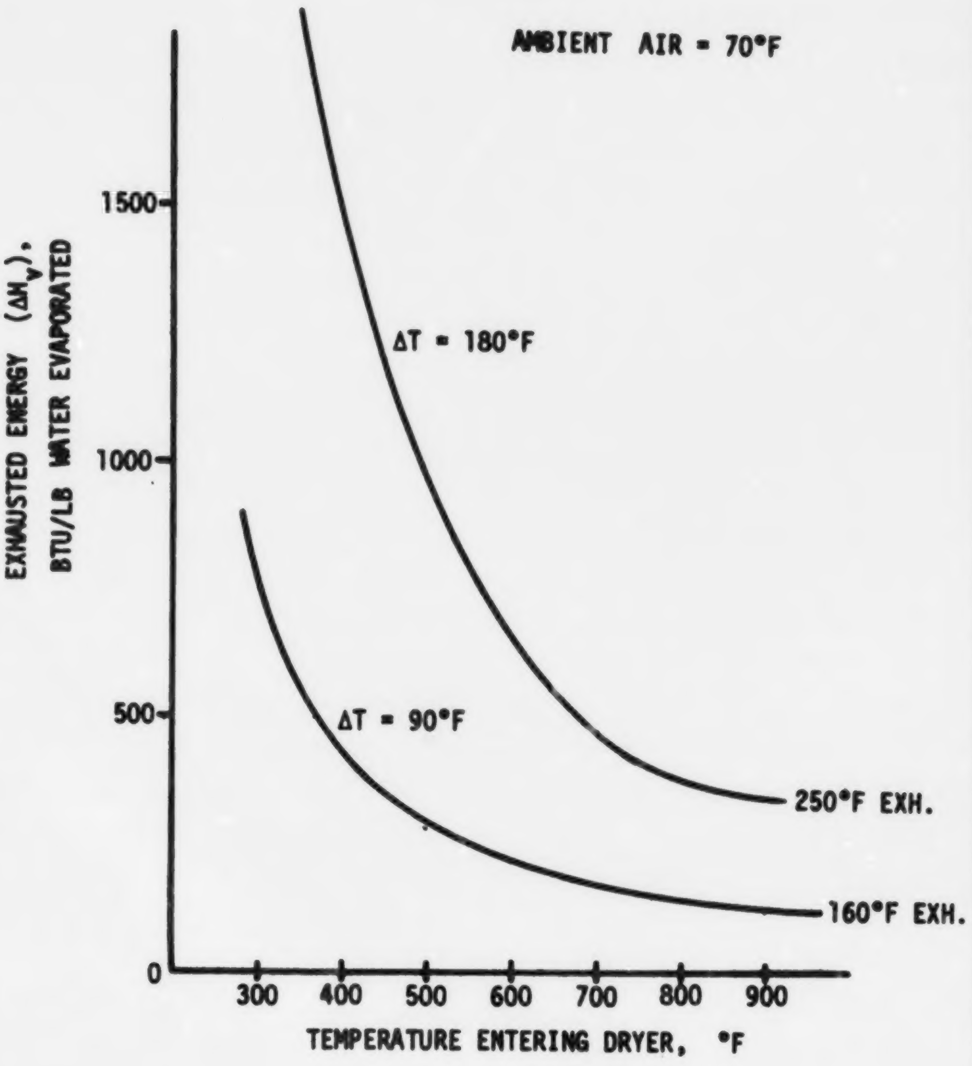


Figure A-3 Energy exhausted to atmosphere in a single-pass particle dryer.

because of the large volumes of air required; these dryers typically require 2200 to 2400 Btu/lb for wet fiber and 2800 to 3000 Btu/lb for particles with initial moisture contents in the range of 20 to 30 percent. Typical ranges of energy consumption for particle dryers are shown in Table A-2.

Table A-2. RANGE OF APPROXIMATE ENERGY USE FOR DRYING PARTICLES (unit production ion volume basis)[4]

	Inlet moisture, %[a]	Exit moisture, %[a]	Energy use, Btu/lb H_2O evaporated	Energy use, million Btu/1000 sq. ft on 3/4" basis
Particleboard				
Dry wood residues	25	5	2000-3000	1.1 - 1.7
Wet wood residues	[illegible]	5	1600-2000	4.2 - 5.2
Green chips (fiber type board)	100	5	2000-25000	5.2 - 6.5

[a] Dry basis.

APPENDIX B:

TERMINOLOGY OF WOOD-BASED FIBER AND PARTICLE PANEL MANUFACTURING

TERMINOLOGY OF WOOD-BASED FIBER AND PARTICLE PANEL MANUFACTURING

Because there is some confusion regarding use of terms describing the basic products of the industry, definitions of ASTM are provided here. Note that the board and panel products are grouped in two basic categories: (1) those manufactured from ligno-cellulosic fibers and fiber bundles, wherein interfelting of the fibers and a natural bond are characteristic; (2) those manufactured from particles that range in size from fine elements approaching fibers to large flakes, which are blended with synthetic resin adhesive and consolidated into boards known as resin-bonded particleboards or more commonly as particleboards.

GENERAL DEFINITIONS

Wood-base fiber and particle panel materials - a generic term applied to a group of board materials manufactured from wood or other ligno-cellulosic fibers or particles to which binding agents and other materials may be added during manufacture to obtain or improve certain properties. Composed of two broad types, fibrous-felted and particleboards.

Fibrous-felted boards - a felted wood-base panel material manufactured of refined or partly refined ligno-cellulosic fibers characterized by an integral bond produced by an interfelting of fibers and in the case of certain densities and control of conditions of manufacture by ligneous bond, and to which other materials may have been added during manufacture to improve certain properties.

Particleboards - a generic term for a panel manufactured from lignocellulosic materials (usually wood) primarily in the form of discrete pieces or particles, as distinguished from fibers, combined with a synthetic resin or other suitable binder and bonded together under heat and pressure in a hot-press by a process in which entire interparticle bond is created by the added binder, and to which other materials may have been added during manufacture to improve certain properties. Particleboards are further defined by the method of pressing. When the pressure is applied in the direction perpendicular to the faces, as in conventional multiplaten hot press, they are defined as flat-platen pressed, and when the applied pressure is parallel to the faces, they are defined as extruded.

Wood-cement board - a panel material where wood usually in the form of excelsior is bonded with inorganic cement.

Classification of Fibrous-felted Boards

Structural insulating board - a generic term for a homogeneous panel made from lignocellulosic fibers (usually wood or cane) characterized by an integral bond produced by interfelting of the fibers, to which other materials may have been added during manufacture to improve certain properties, but which has not been consolidated under heat and pressure as a separate stage in manufacture, said board having a density of less than 31 lb/ft^3 (specific gravity 0.50) but having a density of more than 10 lb/ft^3 (specific gravity 0.16).

Hardboard - a generic term for a panel manufactured primarily from inter-felted lignocellulosic fibers (usually wood), consolidated under heat and pressure in a hot-press to a density of 31 lb/ft^3 (specific gravity 0.50) or greater, and to which other materials may have been added during manufacture to improve certain properties.

Medium-density hardboard - a hardboard as previously defined with a density between 31 and 50 lb/ft^3 (specific gravity between 0.50 and 0.80).

High-density hardboard - a hardboard as previously defined with a density greater than 50 lb/ft^3 (specific gravity 0.80).

Classification of Particleboard

Low-density particleboard - a particleboard as previously defined with a density of less than 37 lb/ft^3 (specific gravity 0.59).

Medium-density particleboard - a particleboard as previously defined with a density between 37 and 50 lb/ft^3 (specific gravity between 0.59 and 0.80).

High-density particleboard - a particleboard as previously defined with a density greater than 50 lb/ft^3 (specific gravity 0.80).

NOTE: It is the industry practice to measure density of particleboards on the basis of moisture content and volume at time of test.

TERMS RELATED TO RAW MATERIALS

The materials used for manufacturing of board and panel products differ in both species and physical characteristics of the furnish material. The species vary with geographical location. In the northwestern states, typical species include Douglas fir, white fir, ponderosa pine, red alder, Englemann spruce, and western hemlock. In the southeastern states, typical species are Southern yellow pine, red oak, yellow birch, and other hardwoods. Care is taken with all species to remove bark from the process raw material.

The physical characteristics of the furnish vary according to the manufacturing processes that produce it; e.g., the furnish may take the form of chips, flakes, planer shavings, or sawdust. Each of these forms has a characteristic size, shape, and moisture content. As an aid in distinguishing the various kinds of feed stock, the following definitions of the ASTM are provided.

Terms Relating to Wood-Base Fiber and Particle Panel Materials

Air-felting - forming of a fibrous-felted board from an air suspension of damp or dry fibers on a batch or continuous forming machine (sometimes referred to as the dry or semi-dry process).

Binder - an extraneous bonding agent, either organic or inorganic, used to bind particles together to produce a particle board.

Chips - small pieces of wood chopped off a block by ax-like cuts as in a chipper of the paper industry, or produced by mechanical hogs, hammermills, etc.

Curls - long flat flakes manufactured by the cutting action of a knife in such a way that they tend to be in the form of a helix.

Fibers - the slender threadlike elements or groups of wood fibers or similar cellulosic material resulting from chemical or mechanical defiberization, or both, and sometimes referred to as fiber bundles.

Flat-platen pressed - a method of consolidating and hot pressing a panel product in which the applied pressure is perpendicular to the faces.

Flake - a small wood particle of predetermined dimensions specifically produced as a primary function of specialized equipment of various types, with the cutting action across the direction of the grain (either radially, tangentially, or at an angle between), the action being such as to produce a particle of uniform thickness, essentially flat, and having the fiber direction essentially in the plane of the flakes, in over-all character resembling a small piece of veneer.

Heat treating - the process of subjecting a wood-base panel material (usually hardboard) to a special heat treatment after hot pressing to increase some strength properties and water resistance.

Hot-pressing - process for increasing the density of a wet-felted or air-felted mat of fibers or particles by pressing the dried, damp, or wet mat between platens of hotpress to compact and set the structure by simultaneous application of heat and pressure.

Particle - the aggregate component of a particle board manufactured by mechanical means from wood or other ligno-cellulose material (comparable to the aggregate in concrete) including all small subdivisions of wood such as chips, curls, flakes, sawdust, shavings, silvers, strands, wood flour, and wood wool. Particle size may be measured by the screen mesh that permits passage of the particles and another screen upon which they are retained, or by the measured dimensions as for flakes and strands.

Sawdust - wood particles resulting from the cutting and breaking action of saw teeth.

Shaving - a small wood particle of indefinite dimensions developed incidental to certain woodworking operations involving rotary cutterheads usually turning in the direction of the grain; and because of this cutting action, producing a thin chip of varying thickness, usually feathered along at least one edge and thick at another and usually curled.

Size - asphalt, rosin, wax, or other additive introduced to the stock for a fibrous-felter board, prior to forming, or added to the blend of particles and resin for a particle board, to increase water resistance.

Slivers - particles of nearly square or rectangular cross-section with a length parallel to the grain of the wood of at least four times the thickness.

Strand - a relatively long (with respect to thickness and width) shaving consisting of flat long bundles of fibers having parallel surfaces.

Tempering - the manufacturing process of adding to a fiber or particle panel material a siccative material such as drying oil blends of oxidizing resin which are stabilized by baking or other heating after introduction.

Wet-felting - forming of a fibrous-felted board mat from a water suspension of fibers and fiber fundles by means of a deckle box, fourdrinier, or cylinder board machine.

Wood flour - very fine wood particles generated from wood reduced by a ball or similar mill until it resembles wheat flour in appearance, and of such a size that the particles usually will pass through a 40-mesh screen.

Wood wool (excelsior) - long, curly, slender strands of wood used as an aggregate component for some particleboards.

The resins used to manufacture board products affect both the quality of the finished product and the environmental emissions. Two types of resin, urea-formaldehyde and phenol-formaldehyde, are used for most manufacturing operations involving particleboard and medium-density board. Urea-formaldehyde is the most common and is suitable for interior use. Phenol-formaldehyde is used where the panel is subjected to extreme heat or humidity or for exterior applications. The resins are carefully "engineered" to meet the specific needs of the manufacturing operation in terms of the wood species and the specifications for strength, fire resistance, moisture resistance, etc., of the finished product.

TERMS RELATED TO FINISHED PRODUCTS

The finished products of the board and panel products industry cover a wide range. The following list includes the categories recognized by the ASTM.

Terms Describing Wood-based Fiber and Particle Panel Products

Acoustical board - a low-density, sound absorbing structural insulating board having a factory-applied finish and a fissured, felted-fiber, slotted or perforated surface pattern provided to reduce sound reflection. Usually supplied for use in the form of tiles.

Building board - a natural finish multi-purpose structural insulating board.

Decorative hardboard - hardboard that is scored or engraved after manufacture or by pressing during manufacture on a patterned caul to produce a decorative surface.

Extruded particleboard - a particleboard manufactured by forcing a mass of particles coated with an extraneous binding agent through a heated die with the applied pressure parallel to the faces and in the direction of extruding.

Hardboard underlayment - a service-grade hardboard made or machined to close thickness tolerances for use as a leveling course and to provide a smooth surface under floor covering materials.

Insulating formboard - a specially fabricated structural insulating board designed for use as a permanent form for certain poured-in-place roof construction.

Interior finish boards - structural insulating board with a factory-applied paint finish, fabricated in the form of plank, board, panels, or tile for interior use.

Intermediate fiberboard sheathing - a high-density structural insulating board sheathing product used in frame construction under masonry veneer, siding, shingles, and stucco.

Insulating roof deck - a structural insulating board product designed for use in openbeam ceiling roof construction. The product is composed of multiple layers of structural insulating board laminated together with water-resistant adhesive.

Mat-formed particleboard - a particleboard in which the coated particles are formed first into a mat having substantially the same length and width as the finished board from being flat-platen pressed.

Nail-base fiberboard sheathing - a specially manufactured, high-density structural insulating board product designed for use in frame construction to permit the direct application of certain exterior siding materials such as wood or cement-asbestos shingles.

Particleboard corestock - common name given to particleboard manufactured for use as a core for overlaying.

Particleboard panel stock - common name given to particleboard manufactured primarily for use as panel material, and in which the surfaces may be treated to obtain decorative effects.

Particleboard underlayment - an underlayment-grade particleboard made or machined to close thickness tolerances for use as a leveling course and to provide a smooth surface under floor covering materials.

Perforated hardboard - hardboard with closely spaced factory punched or drilled holes.

Planed-to-caliper hardboard - hardboard that is machined to a close thickness tolerance.

Prefinished wall panels - hardboards with a factory-applied finish, such as baked-on enamel, lacquer, or similar finish.

Prefinished particleboard - particleboard with a factory-applied finish, such as lacquer, baked-on enamel, or similar finish.

Roof insulation board - structural insulating board fabricated for use as above-deck roof insulation.

Service hardboard - a hardboard of about 55 lb/ft^3 (specific gravity 0.88) density intended for use where standard strength board is not required and better dimensional stability is desired.

Screen-back hardboard (SIS) - hardboard with a reverse impression of a screen on the back produced when a damp or wet mat is hot-pressed into a board and dried in the press.

Sheathing - structural insulating board for use in housing and other building construction, which may be integrally treated, impregnated or coated to give it additional water resistance.

Shingle backer - a specially fabricated sheathing-grade structural insulating board used as a backer strip in coursed shingle construction.

Sound-deadening board - a specially manufactured insulating board product for use in building construction in wall and floor assemblies to reduce sound transmission.

Smooth - two-side hardboard (S2S) - hardboard produced from a dry mat pressed between two smooth hot platens.

Standard hardboard - hardboard substantially as manufactured at the end of hot pressing, except for humidification to adjust moisture content, trimming to size, and other subsequent machining, and having the properties associated with hardboard meeting specifications for that quality product.

Tempered hardboard - a hardboard subjected to tempering as previously defined or specially manufactured with other variation in usual process so that the resulting product has special properties of stiffness, strength, and water-resistance associated with boards meeting specifications for that quality product.

Tempered service hardboard - service hardboard, as previously defined, which as been given a tempering treatment to improve such properties as stiffness, strength, and water resistance.

Subcategories of Particleboard Products

Following is a summary list of particleboard subcategories, based on both end use and on physical parameters of the products.

Corestock - products of flakes or particles, bonded with ureaformaldehyde or phenolic resins with various densities and related properties. For furniture, casework, architectural paneling, doors, and laminated components.

Wood-veneered particleboard - Corestock overlaid at the mill with various wood veneers. For furniture, panels, wainscots, dividers, cabinets, etc.

Overlaid particleboard - particleboard faced with impregnated fiber sheets, hardboard or decorative plastic sheets. For applications such as furniture, doors, wall panelings, sink tops, cabinetry, and store fixtures.

Embossed particleboard - surfaces are heavily textured in various decorative patterns by branding with heated roller. For doors, architectural paneling, wainscots, display units, and cabinet panels.

Filled particleboard - particleboard surface-filled and sanded ready for painting. For painted end-products requiring firm, flat, true surfaces.

Exterior particleboard - Made with phenolic resins for resistance to weathering. For use as an exterior covering material. See FHA UM-32 or consult manufacturer.

Toxic-treated particleboard - particleboard treated with chemicals to resist insects, mold, and decay producing fungi. For tropical or other applications where wood products require protection against insect attack or decay.

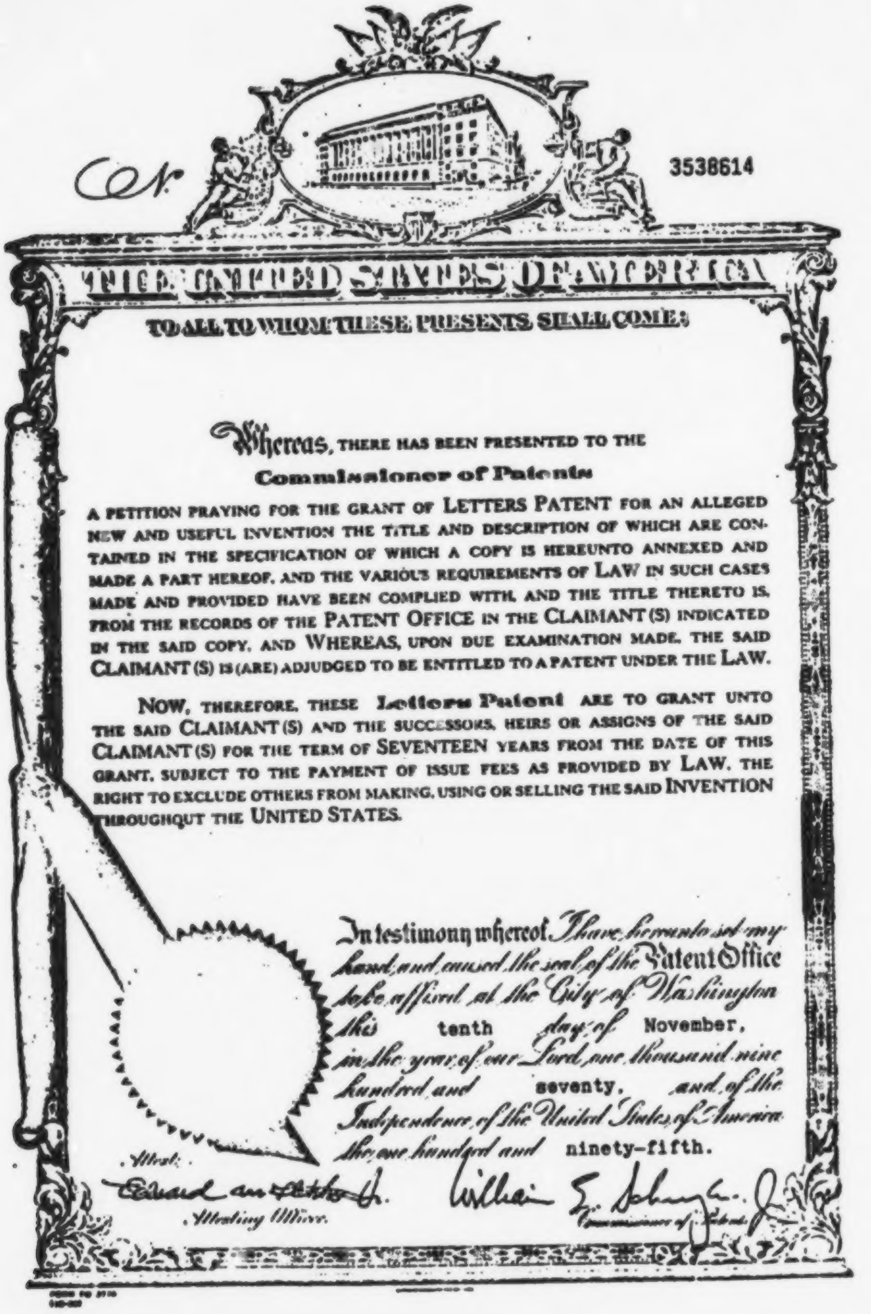
Prime or undercoated - factory-painted base coat on either filled or regular board - exterior or interior. For any painted products.

Floor underlayment - panels specifically engineered for floor underlayment. Underlay for carpets or resilient floor coverings.

Fire-retardant particleboard - particles are treated with fire retardants. For use where building codes require low flame spread material, as in some schools, office buildings, etc.

APPENDIX C

PATENT ON FULL-RECIRCULATION DRYER SYSTEM



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THE UNITED STATES OF AMERICA

TO ALL TO WHOM THESE PRESENTS SHALL COME:

Whereas, THERE HAS BEEN PRESENTED TO THE

Commissioner of Patents

A PETITION PRAYING FOR THE GRANT OF LETTERS PATENT FOR AN ALLEGED NEW AND USEFUL INVENTION THE TITLE AND DESCRIPTION OF WHICH ARE CONTAINED IN THE SPECIFICATION OF WHICH A COPY IS HEREUNTO ANNEXED AND MADE A PART HEREOF, AND THE VARIOUS REQUIREMENTS OF LAW IN SUCH CASES MADE AND PROVIDED HAVE BEEN COMPLIED WITH, AND THE TITLE THERETO IS, FROM THE RECORDS OF THE PATENT OFFICE IN THE CLAIMANT (S) INDICATED IN THE SAID COPY, AND WHEREAS, UPON DUE EXAMINATION MADE, THE SAID CLAIMANT (S) IS (ARE) ADJUDGED TO BE ENTITLED TO A PATENT UNDER THE LAW.

NOW, THEREFORE, THESE **Letters Patent** ARE TO GRANT UNTO THE SAID CLAIMANT (S) AND THE SUCCESSORS, HEIRS OR ASSIGNS OF THE SAID CLAIMANT (S) FOR THE TERM OF SEVENTEEN YEARS FROM THE DATE OF THIS GRANT, SUBJECT TO THE PAYMENT OF ISSUE FEES AS PROVIDED BY LAW, THE RIGHT TO EXCLUDE OTHERS FROM MAKING, USING OR SELLING THE SAID INVENTION THROUGHOUT THE UNITED STATES.

In testimony whereof I have hereunto set my hand and caused the seal of the Patent Office to be affixed at the City of Washington this tenth day of November, in the year of our Lord one thousand nine hundred and seventy, and of the Independence of the United States of America the one hundred and ninety-fifth.

Attest:

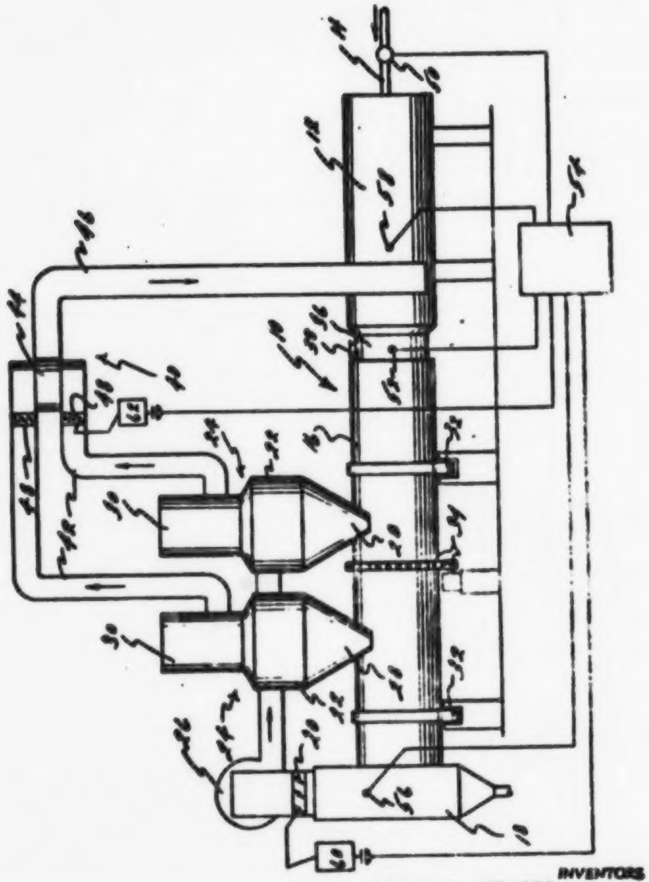
Edward M. Fletcher, Jr.
Attesting Officer.

William E. Schuyler, Jr.
Commissioner of Patents.

Nov. 10, 1970 E. C. WEIMER ET AL 3,538,614

METHOD AND APPARATUS FOR RECYCLING DRYER STACK GASES

Filed Sept. 9, 1968



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METHOD AND APPARATUS FOR RECYCLING DRYER STACK GASES

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U.S. Cl. 34—28 6 Claims

ABSTRACT OF THE DISCLOSURE

This invention relates to an improved method and apparatus for recycling dryer stack gases wherein said gases, along with the solids entrained therein, are drawn off tangentially from the product-recovery cyclones and returned to the system at a point within the combustion zone near the discharge end of the latter where these oxygen-lean recycled stack gases will not inhibit combustion in the furnace, yet will combine with the primary combustion gases to produce a pre-warmed gas mixture for drying the wet pulp in the dryer that will not support combustion therein and is essentially inert in the sense that it will not bring about oxidative degradation of the product. At the same time, the solids are being burned to eliminate them as atmospheric contaminants and their combustion heat is reclaimed to assist in the drying of the product. An essential feature of the system is that all components thereof, together with the stack gases flowing therethrough, be maintained at a temperature above the dew point of the latter so that no condensation can occur.

The conventional pulp-drying installations include a gas-fired furnace whose gaseous products of combustion are fed into a rotating drum-type dryer containing wet pulp. The dried product emerging from the discharge end of the dryer is either recovered directly in a suitable recovery vessel or else sucked up by an induced draft fan and fed to one or more cyclone-type recovery vessels where the dry product is drawn off the bottom while the gaseous elements are discharged through the top. In installations using both primary and secondary product-recovery systems, it is generally recognized that the secondary recovery units (the cyclones) operate more efficiently when they have less product to handle but, even so, some solids still pass into the stack and are discharged into the atmosphere as pollutants. Thus, in both of these types of pulp-drying installations, it would be highly beneficial to be able to recycle the stack gases so as to eliminate or at least further reduce the solids entrained therein. One would naturally expect that a reduction in fuel costs would also result from such a stack gas recycling system.

Despite the obvious advantages attendant to recycling of the dryer stack gases back into the system, the prior art attempts along this line have proven unworkable and have been abandoned. One of the most serious problems encountered was that of the ducts becoming clogged with damp dust. Undoubtedly, other problems were encountered to which no solution was readily apparent and, therefore, further use of the recycling system became undesirable.

It has now been found in accordance with the teaching of the instant invention that a dryer stack gas recycling

system can, in fact, be made to work and, when properly installed and controlled, it will result in a more efficient and cleaner installation. By returning the gases and entrained solids to the system at the proper point, the solids can be incinerated without the oxygen-lean recycled gases acting to inhibit combustion. Also, these same lean recycled gases can be combined with the gaseous products of primary combustion to produce a substantially inert mixture which will not support combustion in the dryer section or bring about detrimental oxidation of the product. By using the recycled stack gases to cool the hot, undiluted primary combustion gases, the conventional practice of using secondary air from the atmosphere as a coolant is eliminated. All components of the recycling system, along with the gases flowing therethrough, must, in accordance with the present invention, be maintained at a temperature somewhat higher than the dew point of these recycled gases; otherwise, the condensible fractions will condense out on the cold surfaces and entrap the entrained solids so as to eventually clog the ductwork.

While the amount of heat recovered by burning the entrained solids is not great, it, together with the heat saved by using the already warm stack gas as secondary air instead of air from the atmosphere, combine to bring about an overall fuel saving of somewhere between 5 and 8%.

In those installations which rely solely on the cyclones for recovery of the dried pulp, the amount of solids escaping with the stack gases is probably going to be greater due to reduced cyclone efficiency when required to handle the entire product output; therefore, the recycling system of the instant invention should prove even more advantageous than in those installations having both primary and secondary product recovery. In both types, however, the pollutants escaping into the atmosphere are going to be largely eliminated and their recovery is unimportant because tests have shown that these solids consist mostly of charred material having little, if any, value.

It is, therefore, the principal object of the present invention to provide a novel and improved method and apparatus for recycling dryer stack gases, along with the fine solids entrained therein.

A second objective is the provision of a dryer stack gas recycling method wherein the temperatures are maintained above the dew point of the gases so as to prevent condensation and the entrapment of solids in said condensate.

Another object of the invention herein disclosed and claimed is to provide a system for recirculating stack gases from a rotating drum dryer installation wherein the already warm recirculated gases are used as a coolant for the hot undiluted products of primary combustion in place of atmospheric air drawn in from the outside at colder ambient temperatures.

Still another objective of the aforementioned invention is to provide a recirculating system for dryer stack gases that largely eliminates the escape of solid pollutants into the atmosphere through the cyclone stacks.

An additional object is to provide a mixture of primary combustion gases and recycled stack gases for introduction into the dryer that is so depleted of its oxygen that it will not support combustion or bring about degradation of the product due to oxidation thereof.

A further object is to provide a stack gas recycling system that is readily incorporated into existing rotary-drum pulp-drying installations, one that results in a material reduction in fuel costs, and a unit of the type aforementioned that results in a better quality and more consistent product.

Other objects will be in part apparent and in part pointed out specifically hereinafter in connection with the detailed description of the single figure of the drawings that shows, somewhat schematically, a conventional rotary-drum-type pulp dryer installation equipped with the stack gas recycling system of the present invention, together with means for effecting automatic control thereof.

Reference numeral 10 designates in a general way a representative pulp-drying installation of the type having a furnace 12 connected to receive gaseous fuel through fuel line 14 and discharge the hot gaseous products of combustion into rotary-drum dryer 16 that contains the pulp (not shown) which is to be dried. The dried product is discharged from the dryer, in the particular installation illustrated, into a primary product-recovery vessel 18 where it is collected from the bottom thereof. The moisture-laden gas from the dryer, carrying somewhere in the neighborhood of 10% of the dried product, is sucked from the discharge end of the dryer through damper 20 and delivered tangentially to the hollow cylindrical midsections 22 of cyclone separators 24 by induced draft fan 26. Most of the product remaining entrained in the moving gas stream is separated centrifugally in the cyclones 24 and is recoverd from the bottom thereof at the outlets of conical sections 28. Ordinarily, the gases, together with whatever solids remain suspended therein that have escaped separation in both the recovery vessel 18 and the cyclones 24, are discharged to the atmosphere through cyclone stacks 30.

It is to just such a pulp-drying installation as that which has been described above that the recycle system of the present invention is added. The furnace section 12 is, of course, stationary and it houses the "combustion zone" of the unit. The hollow cylindrical dryer drum 16 is mounted for slow rotational movement about its longitudinal axis upon trunnion blocks 32 which, in the particular form shown, lie spaced on opposite sides of the gear drive therefor which has been designated by numeral 34.

The intake end of the dryer drum telescopes over stationary tubular throat 36 at the discharge end of the furnace and rotates relative thereto. This tubular throat is provided with a wet pulp intake tube 38 that receives the wet pulp to be dried from some sort of transport mechanism (not shown) like, for example, a screw conveyor. The pulp, therefore, enters the system downstream of the combustion zone where, as will be shown presently, the hot undiluted products of primary combustion in the furnace have been cooled considerably by mixing same with cooler stack gases preparatory to delivering said mixture to the drying zone within the dryer.

At the discharge end of the dryer drum, a primary product recovery vessel 18 has been shown which, as aforesaid, separates somewhere around 90% of the dried product from the system. While such a primary product recovery step is desirable to reduce the cyclone load and thereby increase their efficiency, vessel 18 can be eliminated and the entire output fed directly to the cyclones. In either case, a small proportion of finely-divided solids, usually in the form of charred product which is not worth recovering, passes out the cyclone stacks with the moisture-laden waste gases.

Now, the present invention contemplates the addition of a dryer gas recycle system to the above-described conventional pulp-drying installation, said recycle system having been indicated in a general way on the drawing by reference numeral 40. Ducts 42 are connected tangentially into the stack 30 of each cyclone 24 so as to draw off the stack gases spiralling circumferentially upward on the inside periphery thereof that contain substantially all of the left-over solids, that portion of the stack gas circulating nearer the center of the stack being substantially free of entrained dust. A second induced draft fan 44 connected into these stack ducts 42, sucks the stack gases and entrained solids from the cyclones 24 before they can enter the atmosphere and returns them to the furnace 12 through a return duct 46 at a point adjacent the downstream end of the combustion zone, but ahead of the drying zone and the point at which the wet pulp is introduced. Ducts 42 include dampers 48 that control the volume of gas recycled to the furnace.

It has been mentioned previously that the recycled gas and entrained solids are returned to the furnace adjacent the downstream end of the combustion zone. Since this is a critical factor in the proper operation of the recycle system, it would, perhaps, be wise to amplify some on this point.

To begin with, one of the main objectives of the recycle system is to eliminate the solid pollutants which would otherwise be discharged to the atmosphere. If, as aforementioned, we are going to get rid of these solids by incinerating them, then, obviously, they must be returned to the system at a point where this will occur; otherwise, they would merely continue to circulate through the system in ever-increasing quantities. Thus, it becomes imperative that the solids be returned to the system within the combustion zone where it is still hot enough to incinerate same. On the other hand, the stack gases carrying these solid pollutants ase substantially devoid of oxygen, the oxygen content thereof running generally somewhere around ½ to 1%. If, therefore, this stack gas were returned to the combustion zone near the upstream end thereof where the fuel and oxygen-rich primary combustion air enters the system, its effect would be to retard combustion in the very area where excellent combustion is essential. Furthermore, the recycled stack gases would tend to cool the combustion-zone if introduced near the "lead" or upstream end thereof and it is essential for proper combustion that the fuel flames remain quite hot. Accordingly, it is essential that the stack gases and retained solids be returned to the system far enough downstream in the combustion zone where they will not retard combustion or cool off said zone appreciably. On the other hand, these recycled components must reenter the system where there is enough heat left to incinerate the solids and, as previously stated, these requirements are met by bringing the stack gases back into the system adjacent the downstream or discharge end of the combustion zone.

It so happens that returning the gases and entrained solids to the system at this point also has distinct advantages in terms of fuel savings. While the temperatures in the furnace should be quite hot to insure proper combustion, the gases used to dry the wet pulp must be considerably cooler for best results. Therefore, in the conventional rotating-drum-type dryer installations, secondary air from the atmosphere is mixed with the hot gaseous products of combustion from the furnace to cool off the latter preparatory to indroducing same into the drying zone. This air from the atmosphere is, of course, rich in oxygen when compared with the recycled stack gases, and it is also a great deal cooler.

Use of the recycled stack gases at a temperature of somewhere between approximately 240° F. and 290° F. as the secondary cooling air instead of air drawn from the atmosphere at, say, 70° F., brings about significant savings in fuel costs. Also, the combining of the hot gaseous primary combustion products with the oxygen-lean recycled stack gases results in a mixture which is substantially inert in that it will not support combustion in the drying zone, nor will it contribute to an oxidative degradation of the pulp. To accomplish these ends, the recycled gases must enter the system ahead of the drying zone and ahead of the point where the wet pulp is introduced in order to cool off the primary products of combustion to a temperature of about 1200° F. before they enter the dryer or come into contact with the pulp.

Existing drum-type pulp-drying installations commonly provide for automatic control of the system by regulating the amount of fuel fed to the furnace with an automatic flow control valve 50 connected into fuel line 14. A temperature responsive element 56 located in the primary product recovery vessel in position to measure the temperature of the stack gases leaving the dryer, sends information on the temperature at this point to a suitable control mechanism that has been designated schematically by box 54 and which functions to regulate the fuel flow so as to keep the exhaust gas at a predetermined temperature. Thus, an increase in wet feed material to the dryer tends to reduce the temperature of the exhaust gases, and the control as described functions to open the fuel valve to satisfy the new conditions. A temperature element 52 housed inside the throat 36 sends information on the temperature at this point to the control mechanism 54. This signal will act to override the basic control of the fuel valve should there be a malfunction or if, for any other reason, the temperature in the throat exceeds a preselected value. In addition, the temperature of the moisture-laden exhaust gases ordinarily discharged through the stacks can be maintained at a level above the dew point until it reenters the combustion zone of the system so that no condensation of the condensible fractions contained therein will take place in the recirculation ductwork. Such temperature measurement and fuel flow control is desirable in existing pulp-drying installations, whether controlled manually or automatically, to maintain a uniformly dried product.

In a system like that of the instant invention where the recycled stack gases are used as the source of secondary air to mix with and cool the primary combustion products from the furnace, means must be provided for regulating the latter. In the particular form shown herein, recirculating fan dampers 20 and 48 control the volume of recycled gas returned to the furnace in response to a pressure-sensing element 58 housed inside the combustion zone of the furnace near the point at which the recycled gases enter the latter. In the particular form shown, automatic damper drives 60 and 62 connected to dampers 20 and 48, respectively, operate the latter in response to signals fed thereto from the control mechanism 54 which acts in accordance with information fed thereto by the temperature and pressure sensors. The system can, of course, be controlled manually based upon this same temperature and pressure information, and no particular novelty resides in doing so automatically; therefore, no useful purpose would be served by going into a detailed explanation of the automatic control circuitry, especially when the apparatus necessary to accomplish manual control thereof has already been described and illustrated.

As previously stated, the gas recirculated back through the system will ordinarily have a temperature between approximately 240° F. and 290° F. but, in all cases, its temperature must be above its dew point to eliminate unwanted condensation in the ductwork. The dew point temperature, of course, varies with the pressure and degree of saturation of the exhaust gases, a fact well-known to any competent engineer and one, therefore, that is readily determined under existing operating conditions.

Finally, a few words about the ductwork shown in the accompanying drawing. The illustrated dryer installation including two cyclone separators is, of course, intended as being merely representative of many different arrangements that can be used including only one or several such separators, the stack gases from which are combined and returned to the combustion zone. Alternatively, there is no need for introducing the recirculated gases through a single return duct 46. In fact, a better balanced system would certainly result if the flow of recycled gases was split and introduced into opposite sides of the furnace, the return duct on the back side being hidden by the one shown, but being functionally identical thereto.

Having thus described the several useful and novel features of the instant method and apparatus for recycling dryer stack gases, it will be apparent that the several worthwhile objectives for which the device was developed have been achieved. Although but a single embodiment of the invention has been illustrated and described, we realize that certain changes and modifications therein may well occur to those skilled in the art within the broad teaching herein; hence, it is our intention that the scope of protection afforded hereby shall be limited only insofar as said limitations are expressly set forth in the appended claims.

What is claimed is:

1. In combination in a pulp-drying plant: of the type having a gas-fired furnace connected to deliver the hot gaseous products of combustion generated therein to the intake end of a drum dryer rotating about its longitudinal axis, means for delivering wet pulp to the intake end of the dryer drum, means comprising a cyclone separator for centrifugally separating the major portion of the solid constituents into a recovery vessel at the bottom thereof while exhausting the gaseous constituents along with the solids remaining suspended therein through a stack at the top, a pneumatic conveyor means including a damper-controlled duct containing an induced draft fan connected to receive the gaseous products along with the solids entrained therein from the discharge end of the dryer drum and deliver same tangentially to the cyclone separator, and means for recycling the stack gases containing the major portion of residual solids and removing the latter therefrom, said means including duct means having the inlet end thereof connected tangentially into the cyclone stack in position to draw off that portion of the exhaust gases spiralling upwardly therein containing the major portion of the residual solids and its outlet connected to return the latter to the furnace at a point downstream of its combustion zone where the hot gaseous products of combustion will incinerate the solids and be cooled by the recycled stack gases preparatory to contacting the wet pulp at the intake end of the dryer drum, induced draft fan means mounted in the duct means operative to draw the stack gases and entrained residual solids from the cyclone stack and deliver same to the furnace, damper means mounted within the duct means operative upon actuation to control the flow of recycled gas, and control means responsive to the temperature of the moisture-laden gases leaving the dryer drum operative to actuate the damper-controlled duct so as to regulate the gas flow to the cyclone separator.

2. In a process for drying wet pulp of the type wherein the hot dry gaseous products of primary combustion generated within the combustion zone of gas-fired furnace are first cooled and passed in heat-exchange relation to wet pulp being tumbled in a rotary drum dryer, then sucked from the discharge end of the dryer drum and delivered tangentially by an induced draft fan to a cyclone separator where the major portion of any suspended solids are separated therefrom centrifugally and collected and finally discharged by circulating same up the cyclone stack, the improved method for removing any residual solids left in the exhaust gases while using the latter to cool the hot gaseous products of primary combustion which comprises: drawing off the exhaust gases tangentially from the cyclone stack so as to divert that portion thereof containing most of the residual solids suspended therein and delivering same to the furnace downstream of the combustion zone, said exhaust gases being allowed to cool to a temperature no less than the dew point thereof before reentering the furnace, said exhaust gases being mixed with the hot dry gaseous product of primary combustion to cool the latter and form a substantially inert oxygen-lean mixture therewith that will not support combustion in the dryer drum, and said suspended residual solids being incinerated by said hot gaseous products of primary combustion.

3. The method as set forth in claim 2 in which: the exhaust gases are cooled to a temperature between ap-

proximately 240° F. and 290° F. but no lower than the dew point thereof before reentering the furnace.

4. The method as set forth in claim 2 in which: volume and temperature of the exhaust gases are controlled in relation to the volume and temperature of the hot gaseous products of primary combustion such that the mixture thereof enters the dryer drum at a temperature of approximately 1200° F.

5. The method as set forth in claim 4 in which: the exhaust gases are allowed to cool to a temperature no less than the dew point thereof before reentering the furnace.

6. The method as set forth in claim 4 in which: the exhaust gases are cooled to a temperature between approximately 240° F. and 290° F. but no lower than the dew point thereof before reentering the furnace.

References Cited

UNITED STATES PATENTS

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2,143,505	1/1939	Arnold	34—28
2,715,283	8/1955	Halldorsson	34—79

EDWARD J. MICHAEL, Primary Examiner

U.S. Cl. X.R.

34—79, 131

IN THE UNITED STATES PATENT OFFICE

Applicant : Ervin C. Weimer et al
Serial No. : 758,412
Filed : September 9, 1968
For : METHOD AND APPARATUS FOR RECYCLING DRYER STACK GASES

Examiner : E.J. Michael
Paper No. : 3
Group : 344
Denver, Colorado
February 9, 1970

Hon. Commissioner of Patents
Washington, D.C. 20231

Sir:

AMENDMENT

Responsive to the Office action of November 12, 1969, please enter the following amendments:

In the Claims:

Rewrite claim 4 in independent form as follows.

4. (Amended) In combination in a pulp-drying plant; of the type having a gas-fired furnace connected to deliver the hot gaseous products of combustion generated therein to the intake end of a drum dryer rotating about its longitudinal axis, means for delivering wet pulp to the intake end of the dryer drum, means comprising a cyclone separator for centrifugally separating the major portion of the solid constituents into a recovery vessel at the bottom thereof while exhausting the gaseous constituents along with the solids remaining suspended therein through a stack at the top, [and] a pneumatic conveyor means including a damper-controlled duct containing an induced draft fan connected to receive the gaseous products along with the solids entrained therein from the discharge end of the dryer drum and deliver same tangentially to the cyclone separator, [the improved apparatus] and means for recycling the stack gases containing the major portion of residual solids and removing the latter therefrom, [which comprises:] said means including duct means having the inlet end thereof connected tangentially into the cyclone stack in position to draw off that portion of

the exhaust gases spiralling upwardly therein containing the major portion of the residual solids and its outlet connected to return the latter to the furnace at a point downstream of its combustion zone where the hot gaseous products of combustion will incinerate the solids and be cooled by the recycled stack gases preparatory to contacting the wet pulp at the intake end of the dryer drum, induced draft fan means mounted in the duct means operative to draw the stack gases and entrained residual solids from the cyclone stack and deliver same to the furnace, [and] damper means mounted within the duct means operative upon actuation to control the flow of recycled gas, and [The improved stack gas recycling apparatus as set forth in Claim 1 which includes:] control means responsive to the temperature of the moisture-laden gases leaving the dryer drum operative to actuate the damper-controlled duct so as to regulate the gas flow to the cyclone separator.

6. (Amended) In a process for drying wet pulp of the type wherein the hot dry gaseous products of primary combustion generated within the combustion zone of a gas-fired furnace are first cooled and passed in heat-exchange relation to wet pulp being tumbled in a rotary drum dryer, then sucked from the discharge end of the dryer drum and delivered tangentially by an induced draft fan to a cyclone separator where the major portion of any suspended solids are separated therefrom centrifugally and collected and finally discharged by circulating same up the cyclone stack, the improved method for removing any residual solids left in the exhaust gases while using the latter to cool the hot gaseous products of primary combustion which comprises: drawing off the exhaust gases tangentially from the cyclone stack so as to divert that portion thereof containing most of the residual solids suspended therein and delivering same to the furnace downstream of the combustion zone, [The method

as set forth in Calim 5 in which [the] said exhaust gases [are] being allowed to cool to a temperature no less than the dew point thereof before reentering the furnace, said exhaust gases being mixed with the hot dry gaseous product of primary combustion to cool the latter and form a substantially inert oxygen-lean mixture therewith that will not support combustion in the dryer drum, and said suspended residual solids being incinerated by said hot gaseous products of primary combustion.

Claim 8, line 1;

Delete "Claim 5" and substitute --- Claim 6 ---.

Cancel claims 1-3 and 5 without prejudice.

REMARKS

Claim 4 has been rewritten in independent form as suggested and claim 6 has also been rewritten as an independent claim. Claims 1-3 and 5 have been concelled without prejudice.

Amended claim 4 is essentially original claim 1 plus old claim 4. The form was changed to a combination claim to provide a better antecedent basis for the words of old claim 4. Since old claim 4 was indicated allowable if rewritten in independent form, amended claim 4 should now be allowable.

Claim 6 as rewritten is essentially original claim 5 plus the words of original claim 6. The method claimed in amended claim 6 is not anticipated by any of the three cited references.

The method as now claimed definitely requires the recycled gases to remain at all times above the dew point temperature. Neither Halldorsson, Arnold nor Burns disclose this requirement. In fact, in Halldorsson it is specifically provided that the recycled gases will condense in the wash tower W. Column 6, lines 24-39. Furthermore, none of the references even touches on the problems associated with condensate forming on the inside walls of the return duct work.

As stated by the Examiner, there will obviously be some cooling of the recycled gases in all of the devices disclosed by the cited references. The value to which cooling is permitted in applicants' device, however, is very critical and, contrary to the Examiner's statement, is one of the primary novel features of applicants' invention. It was the exact problem of condensate forming on the inside of the ductwork, not at all considered in Halldorsson, Arnold or Burns, which applicants set out to solve. It is submitted that applicants' invention has solved this problem in a manner not taught or anticipated by the references.

Claims 7-10 are re-submitted for consideration in view of the above remarks and inasmuch as they are merely narrower limitations on amended claim 6.

Based on the above remarks, it is believed that amended claims 4, 6 and 8 and original claims 7, 9 and 10 are in condition for allowance and prompt action to this end will be appreciated.

Respectfully submitted,

ANDERSON, SPANGLER & WYMORE

By
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Area Code 303
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ELS:tg

APPENDIX D

SUMMARY DATA SHEETS FOR 76 PARTICLE AND FIBER DRYERS

DRYER NO.	1	2	3	4	5	6	7	8	9	10	11	12
PROCESS: HARDBOARD (FIBERS)												
PARTICLEBOARD (PARTICLES)	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
DRYER TYPE: TUBE (INLINE)												
FLASH		✓	✓									
STATIONARY DRUM												
ROTARY SINGLE PASS DRUM	✓											
ROTARY TRIPLE PASS DRUM				✓	✓	✓	✓	✓	✓	✓	✓	✓
DRYER SYSTEM: SINGLE DRYER	✓			✓	✓	✓	✓	✓	✓	✓	✓	✓
1st DRYER IN SERIES		✓										
2nd DRYER IN SERIES			✓									
YEAR INSTALLED:		1962	1962									
FURNISH: SURFACE	HOMO.	HOMO.	HOMO.	HOMO. →			HOMO.	HOMO.	HOMO.	HOMO.	HOMO.	HOMO.
CORE												
MATERIAL FEED RATE (LBS/HR DRY BASIS)	40,500	40,500	40,500	15,600	15,600	15,600	15,600	31,300	31,300	10,000	4,000	10,000
INLET MOISTURE (%)	20-40	20-25	10	12-15	12-15	12-15	12-15	40-50	40-50	36-60	30-60	12-15
EXIT MOISTURE (%)	20-25	10	5-6	4-5	4-5	4-5	4-5	12-15	12-15	4-5	4-5	4-5
INLET GAS TEMP. (°F)	800	550	400	250-300	250-300	250-300	250-300	400-700	400-700	800-1000	800-1000	800-1000
EXIT GAS TEMP. (°F)	250	200+	150	165	165	165	165	190-220	190-220	175-235	175-235	175-235
EXIT GAS FLOW RATE (ACFM x 1000)	36.5							12.8		8.1 SCFM	9.5 SCFM	5.6 SCFM
MOST COMMON SPECIES	D. FIR	D. FIR	D. FIR	D. FIR	D. FIR	D. FIR	D. FIR	D. FIR	D. FIR	D. FIR	D. FIR	D. FIR
MATERIAL SIZE RANGE												
PRIMARY ENERGY SOURCE	SAND. DUST	SAND. DUST	SAND. DUST	STM	STM	STM	STEAM	NAT. GAS	NAT. GAS	SAND. DUST	SAND. DUST	SAND. DUST
SECONDARY ENERGY SOURCE	HOGGED WOOD	HOG. WOOD	HOG. WOOD	NAT. GAS	NAT. GAS	NAT. GAS	NAT. GAS	BLR. STM.	BLR. STM.	PROPANE	PROPANE	PROPANE
BACKUP ENERGY SOURCE	STRAW	STRAW	STRAW					DIESEL	DIESEL			
NON RECYCLE SYSTEM			✓	✓	✓	✓	✓	✓	✓			
PARTIAL RECYCLE SYSTEM												
FULL RECYCLE SYSTEM	✓	✓								✓	✓	✓
UNCONTROLLED SYSTEM: LBS/HR												
gr/SDCF								0.123	0.167			
OPACITY (%)			<10					>20	>20			
CONTROLLED SYSTEM: WET SCRUBBER				✓	✓	✓	✓		✓			
FULL RECYCLE	✓	✓								✓	✓	✓
PARTIAL RECYCLE												
MED. EN. SECONDARY CYC.												
MULTIPLE CYCLONES												
FABRIC FILTER												
OTHER												
COST OF CONTROLLED SYSTEM: CAPITAL (1000 $)	385 TOTAL →			140 TOTAL - DRYERS		4,5,6,&7	SEE #4,5,6			450 TOTAL →		
OP. EXPENSE (1000 $)				40 "	"	4,5,6,&7	SEE #4,5,6					
ANNUAL MAINTENANCE ($)												
ENERGY REQUIREMENTS: (HORSEPOWER)				295 TOTAL - DRYERS		4,5,6,&7	SEE #4,5,6					
CONTROLLED EMISSIONS: gr/SDCF	0.072								0.049	0.121	0.152	0.08
OPACITY (%)	0	0		0	0	0	0		10-20	<10	<10	<3
EMISSION TEST METHOD: HI-VOLUME									✓			
EPA METHOD 5												
S - 8 VENEER DRYER	✓									✓	✓	✓

DRYER NO.	13	14	15	16	17	18	19	20	21	22	23	24
PROCESS: HARDBOARD (FIBERS)												✓
PARTICLEBOARD (PARTICLES)	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
DRYER TYPE: TUBE (INLINE)												
FLASH												
STATIONARY DRUM												
ROTARY SINGLE PASS DRUM												
ROTARY TRIPLE PASS DRUM	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	
DRYER SYSTEM: SINGLE DRYER	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
1st DRYER IN SERIES												
2nd DRYER IN SERIES												
YEAR INSTALLED:									1974	1974	1971	1975
FURNISH: SURFACE	✓	✓	✓	✓							HOMO.	✓
CORE					✓	✓	✓	✓	✓			
MATERIAL FEED RATE (LBS/HR DRY BASIS)	42,000	42,000	42,000	42,000	42,000	42,000	42,000	42,000			20-30,000	14-16,000
INLET MOISTURE (%)	50	50	50	50	25-30	25-30	25-30	25-30	100	100	20-60	45-85
EXIT MOISTURE (%)	25-30	25-30	25-30	25-30	5	5	5	5	25-30	25-30	5-6	10
INLET GAS TEMP. (°F)	480	480	480	480	480	480	480	480	220	220	1000-1600	450
EXIT GAS TEMP. (°F)	180	180	180	180	180	180	180	180	206	206	195-215	210
EXIT GAS FLOW RATE (ACFM x 1000)					38.6 SDCFM						16.2 SCFM	46.0 SCFM
MOST COMMON SPECIES	D.FIR	D.FIR	D.FIR	D.FIR	D. FIR	D.FIR	D.FIR	D.FIR	D. FIR	D.FIR	D.FIR	D.FIR
MATERIAL SIZE RANGE												
PRIMARY ENERGY SOURCE	STM	STM	STM	STM	STM	STM	STM	STM	STM	STM	SAND. DUST	NAT. GAS
SECONDARY ENERGY SOURCE	NAT. GAS	NAT. GAS	NAT. GAS	NAT. GAS	NAT. GAS	NAT. GAS	NAT. GAS	NAT. GAS			NAT. GAS	PROPANE
BACKUP ENERGY SOURCE	PROPANE	PROPANE	PROPANE	PROPANE	PROPANE	PROPANE					FUEL OIL	STM
NON RECYCLE SYSTEM	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	
PARTIAL RECYCLE SYSTEM												✓ NOT USED
FULL RECYCLE SYSTEM												
UNCONTROLLED SYSTEM: LBS/HR												
gr/SDCF											0.50	0.01
OPACITY (%)									<10		100	0
CONTROLLED SYSTEM: WET SCRUBBER	✓	✓	✓	✓	✓	✓	✓	✓				
FULL RECYCLE												
PARTIAL RECYCLE												
MED. EN. SECONDARY CYC.												
MULTIPLE CYCLONES												
FABRIC FILTER												
OTHER												
COST OF CONTROLLED SYSTEM: CAPITAL (1000 $)												
OP. EXPENSE (1000 $)												
ANNUAL MAINTENANCE ($)												
ENERGY REQUIREMENTS: (HORSEPOWER)												
CONTROLLED EMISSIONS: gr/SDCF					0.08							
OPACITY (%)	<10	<10	<10	<10	<10	<10	<10	<10				
EMISSION TEST METHOD: HI-VOLUME					✓						✓	✓
EPA METHOD 5												
S - 8 VENEER DRYER												

DRYER NO.	25	26	27	28	29	30	31	32	33	34	35	36
PROCESS: HARDBOARD (FIBERS)	✓											✓
PARTICLEBOARD (PARTICLES)		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	
DRYER TYPE: TUBE (INLINE)	✓					✓	✓	✓	✓			✓
FLASH		✓	✓									
STATIONARY DRUM												
ROTARY SINGLE PASS DRUM												
ROTARY TRIPLE PASS DRUM				✓	✓							
DRYER SYSTEM: SINGLE DRYER	✓									✓	✓	
1st DRYER IN SERIES		✓		✓		✓	✓			✓	✓	✓
2nd DRYER IN SERIES			✓		✓			✓	✓			
YEAR INSTALLED:	1975	1965	1965			1970	1970	1970	1970	1970	1970	
FURNISH: SURFACE						✓	✓	✓	✓			HOMO.
CORE	✓	✓	✓	✓	✓					✓	✓	
MATERIAL FEED RATE (LBS/HR DRY BASIS)	14-16,000					20,000	20,000	20,000	20,000	35,000	35,000	3,000
INLET MOISTURE (%)	45-85	43	12-15	43	12-15	8-10	8-10	4-5	4-5	8-10	8-10	35
EXIT MOISTURE (%)	6-4	12-15	3-4	12-15	3-4	4-5	4-5	3-4	3-4	3-4	3-4	16
INLET GAS TEMP. (°F)	450	550	300	800	600	220	220	175	175	300	300	325-340
EXIT GAS TEMP. (°F)	210	160	205	160	220					180	180	165
EXIT GAS FLOW RATE (ACFM x 1000)	51 SCFM	32	24	8.7 SCFM	3.5 SCFM							13
MOST COMMON SPECIES	D.FIR	D.FIR	D.FIR	D.FIR	D.FIR	P.PINE	P.PINE	P.PINE	P.PINE	P.PINE	P.PINE	P.PINE
MATERIAL SIZE RANGE												
PRIMARY ENERGY SOURCE	NAT.GAS	SAND.DUST	SAND.DUST	SAND.DUST	SAND.DUST	STEAM	STEAM	STEAM	STEAM	BLR. STR.	OIL	STEAM
SECONDARY ENERGY SOURCE	PROPANE	NAT.GAS	NAT. GAS	NAT. GAS	NAT. GAS					OIL		
BACKUP ENERGY SOURCE		PROPANE	PROPANE	PROPANE	PROPANE							
NON RECYCLE SYSTEM		✓	✓			✓	✓	✓	✓	✓	✓	✓
PARTIAL RECYCLE SYSTEM												
FULL RECYCLE SYSTEM	✓ NOT USED			✓	✓							
UNCONTROLLED SYSTEM: LBS/HR						1	1	2	1	2	2	
gr/SDCF	0.16											0.04
OPACITY (%)	<10					0	0	0	0	<10	<10	0
CONTROLLED SYSTEM: WET SCRUBBER		✓	✓									
FULL RECYCLE				✓	✓							
PARTIAL RECYCLE												
MED. EN. SECONDARY CYC.												
MULTIPLE CYCLONES												
FABRIC FILTER												
OTHER												
COST OF CONTROLLED SYSTEM: CAPITAL (1000 $)		32	24									
OP. EXPENSE (1000 $)												
ANNUAL MAINTENANCE ($)		1000	1000	1000	1000							
ENERGY REQUIREMENTS: (HORSEPOWER)												
CONTROLLED EMISSIONS: gr/SDCF		0.02	0.02	0.09	0.08							
OPACITY (%)		<5	<5	<5	<5							
EMISSION TEST METHOD: HI-VOLUME						✓	✓	✓	✓	✓	✓	✓
EPA METHOD 5												
S - 8 VENEER DRYER				✓	✓							

DRYER NO.	37	38	39	40	41	42	43	44	45	46	47	48
PROCESS: HARDBOARD (FIBERS)	✓	✓	✓					✓	✓	✓		
PARTICLEBOARD (PARTICLES)				✓	✓	✓	✓				✓	✓
DRYER TYPE: TUBE (INLINE)	✓	✓	✓									
FLASH												
STATIONARY DRUM												
ROTARY SINGLE PASS DRUM												
ROTARY TRIPLE PASS DRUM				✓	✓	✓	✓	✓	✓	✓	✓	✓
DRYER SYSTEM: SINGLE DRYER	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
1st DRYER IN SERIES												
2nd DRYER IN SERIES												
YEAR INSTALLED:				1964	1969	1969	1973	1952	1956	1971	1971	1971
FURNISH: SURFACE	HOMO.	HOMO.	HOMO.	HOMO.	HOMO.	HOMO.	HOMO.	HOMO.	HOMO.	HOMO.	✓	
CORE												✓
MATERIAL FEED RATE (LBS/HR DRY BASIS)	3,000	3,000	6,300	20-45,000	20-45,000	20,-45,000	20-45,000	2.4-3,600	4.8-6,600	2.4-3,600	45-50,000	40-50,000
INLET MOISTURE (%)	85	35	35	12-15	12-15	15-105	12-15	50	50	50	15-18	15-18
EXIT MOISTURE (%)	16	16	16	3-5	3-5	12-15	3-5	8	8	8	5-7	5-7
INLET GAS TEMP. (°F)	325-340	325-340	340-360	160-200	160-200	450-500	160-200	385-550	385-550	385-550	300-400	300-400
EXIT GAS TEMP. (°F)	165	165	165	120-160	120-160	160-200	120-160	150-190	150-190	150-190	150-160	150-160
EXIT GAS FLOW RATE (ACFM x 1000)	13	14	11	33	33	33	33	22	33	21	71	44
MOST COMMON SPECIES	P. PINE	P. PINE	P. PINE	P. PINE	P. PINE	P. PINE	P. PINE	D. FIR	D. FIR	D. FIR	D. FIR	D. FIR
MATERIAL SIZE RANGE												
PRIMARY ENERGY SOURCE	STM	STM	STM	STM	STM	BLR. STK	STM	NAT. GAS	NAT. GAS	NAT. GAS	SAND, DUST	SAND. DUST
SECONDARY ENERGY SOURCE				NAT. GAS	NAT. GAS		HOT H_2O				NAT. GAS	NAT. GAS
BACKUP ENERGY SOURCE												
NON RECYCLE SYSTEM	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
PARTIAL RECYCLE SYSTEM												
FULL RECYCLE SYSTEM												
UNCONTROLLED SYSTEM: LBS/HR												
gr/SDCF	0.05	0.05	0.02								0.06-0.09	
OPACITY (%)	0	0	0						10-20	10-20	<10	
CONTROLLED SYSTEM: WET SCRUBBER				✓	✓	✓	✓					
FULL RECYCLE												
PARTIAL RECYCLE												
MED. EN. SECONDARY CYC.												✓
MULTIPLE CYCLONES												
FABRIC FILTER								✓				
OTHER												
COST OF CONTROLLED SYSTEM: CAPITAL (1000 $)				310 TOTAL FOR 40---43			SEE 40,41,42	65				134
OP. EXPENSE (1000 $)												
ANNUAL MAINTENANCE ($)												
ENERGY REQUIREMENTS: (HORSEPOWER)												75
CONTROLLED EMISSIONS: gr/SDCF				0.003	0.018	0.071	0.002					0.06
OPACITY (%)				<5	<5	<5	<5					10-15
EMISSION TEST METHOD: HI-VOLUME	✓	✓	✓	✓			✓					
EPA METHOD 5					✓	✓						
S - 8 VENEER DRYER											✓	✓

DRYER NO.	49	50	51	52	53	54	55	56	57	58	59	60
PROCESS: HARDBOARD (FIBERS)				✓					✓	✓		
PARTICLEBOARD (PARTICLES)	✓	✓	✓		✓	✓	✓	✓			✓	✓
DRYER TYPE: TUBE (INLINE)												
FLASH												
STATIONARY DRUM			✓						✓	✓		
ROTARY SINGLE PASS DRUM												
ROTARY TRIPLE PASS DRUM	✓	✓		✓	✓	✓	✓	✓			✓	✓
DRYER SYSTEM: SINGLE DRYER	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
1st DRYER IN SERIES												
2nd DRYER IN SERIES												
YEAR INSTALLED:	1974	1974	1965		1973	1973	1967	1967	1959	1959	1974	1974
FURNISH: SURFACE	PRE DRYERS	PRE DRYER			✓	✓	✓		HOMO	HOMO.		
CORE								✓			✓	✓
MATERIAL FEED RATE (LBS/HR DRY BASIS)	60,000	60,000	20-30,000		8000	20,000	24,000	24,000	15,000	15,000	19,000	19,000
INLET MOISTURE (%)	50	50	15-18		100	22	25	25	50	50	85	85
EXIT MOISTURE (%)	15-18	15-18	5-7		22	5	9	7	7	7	3	3
INLET GAS TEMP. (^{0}F)	600-900	600-900		250							800	800
EXIT GAS TEMP. (^{0}F)	220-225	220-2	144-148	150	60	135	125	125	159	180	200	200
EXIT GAS FLOW RATE (ACFM x 1000)	47	48	22	9.5 SCFM	27	11.3 SCFM	34.5	37.5	46.0 SCFM	46.0 SCFM		
MOST COMMON SPECIES	D.FIR	D.FIR	D.FIR	PINE	PINE	PINE	PINE	PINE	HARDWOOD	HARDWOODS	PINE	PINE
MATERIAL SIZE RANGE					SAWDUST	6MM SCREEN	10 MESH	4 MESH			< 3/4"	< 3/4"
PRIMARY ENERGY SOURCE	SAND. DUST	SAND. DUST	SAND. DUST	STEAM	NAT. GAS	NAT. GAS	NAT. GAS	NAT. GAS	NAT. GAS	NAT. GAS	SAND. DUST	SAND. DUST
SECONDARY ENERGY SOURCE	NAT. GAS	NAT. GAS	NAT. GAS		FUEL OIL	FUEL OIL	FUEL OIL	FUEL OIL	PROPANE	PROPANE	HOG. FUEL	HOG. FUEL
BACKUP ENERGY SOURCE							SAND. DUST	SAND. DUST			BLR. STK	BLR. STK
NON RECYCLE SYSTEM				✓	✓	✓	✓	✓	✓	✓		
PARTIAL RECYCLE SYSTEM	✓	✓									40%	40%
FULL RECYCLE SYSTEM												
UNCONTROLLED SYSTEM: LBS/HR												
gr/SDCF				0.08			0.009	0.005				
OPACITY (%)				0			~20	~20			5-10	5-10
CONTROLLED SYSTEM: WET SCRUBBER												
FULL RECYCLE												
PARTIAL RECYCLE												
MED. EN. SECONDARY CYC.			✓		✓	✓			✓	✓		
MULTIPLE CYCLONES												
FABRIC FILTER												
OTHER	PAR. RECYC.	PAR RECYC									TO BLR.	TO BLR
COST OF CONTROLLED SYSTEM: CAPITAL (1000 $)			95						500	500	500	500
OP. EXPENSE (1000 $)												
ANNUAL MAINTENANCE ($)									7500	7500		
ENERGY REQUIREMENTS: (HORSEPOWER)			80			150			450	450	125	125
CONTROLLED EMISSIONS: gr/SDCF	0.18	0.09	0.05			0.029			0.035	0.063		
OPACITY (%)	10-15	10-15	10-15			0			0	0		
EMISSION TEST METHOD: HI-VOLUME				✓		✓	✓	✓	✓	✓		
EPA METHOD 5												
S - 8 VENEER DRYER	✓	✓	✓									

DRYER NO.		61	62	63	64	65	66	67	68	69	70	71	72
PROCESS:	HARDBOARD (FIBERS)				✓	✓	✓	✓	✓	✓	✓	✓	✓
	PARTICLEBOARD (PARTICLES)	✓	✓	✓									
DRYER TYPE:	TUBE (INLINE)							✓	✓	✓	✓	✓	✓
	FLASH				✓	✓	✓						
	STATIONARY DRUM												
	ROTARY SINGLE PASS DRUM	✓											
	ROTARY TRIPLE PASS DRUM		✓	✓									
DRYER SYSTEM:	SINGLE DRYER	✓	✓	✓	✓	✓	✓						
	1st DRYER IN SERIES							✓	✓	✓			
	2nd DRYER IN SERIES										✓	✓	✓
YEAR INSTALLED:		1960	1972	1972	1973	1973	1973	1970	1970	1970	1970	1970	1970
FURNISH:	SURFACE	✓	HOMO.	HOMO.	HOMO.	HOMO.	HOMO.	HOMO.	HOMO.	HOMO.	HOMO.	HOMO.	HOMO.
	CORE												
MATERIAL FEED RATE (LBS/HR DRY BASIS)		6,500	5,000	9,000	12,000	12,000	12,000	12,500	12,500	12,500	12,500	12,500	12,500
INLET MOISTURE (%)		90	80	20	54	54	54	82	82	82	43	43	43
EXIT MOISTURE (%)		25	5	5	5	5	5	43	43	43	5	5	5
INLET GAS TEMP. (°F)		600	800-1000	600-800	625	625	625	300	300	300	375	375	375
EXIT GAS TEMP. (°F)		200	225	140	220	220	220	270	270	270	170	170	170
EXIT GAS FLOW RATE (ACFM x 1000)			37.0 SCFM	45.0 SCFM	59	59	59	15.7	15.7	15.7	15.7	15.7	15.7
MOST COMMON SPECIES		PINE	PINE	PINE	HARDWOODS	HARDWOODS	HARDWOODS	HARDWOODS	HARDWOODS	HARDWOODS	HARDWOODS	HARDWOODS	HARDWOODS
MATERIAL SIZE RANGE		< 3/8"	SAWDUST	PLNR. SHAV	"FINES"	"FINES"	"FINES"	< 1/2"	< 1/2"	< 1/2"	< 1/2"	< 1/2"	< 1/2"
PRIMARY ENERGY SOURCE		SAND. DUST	FUEL OIL	FUEL OIL	NAT. GAS	NAT. GAS	NAT. GAS	STM	STM	STM	NAT. GAS	NAT. GAS	NAT. GAS
SECONDARY ENERGY SOURCE		HOG. FUEL			FUEL OIL	FUEL OIL	FUEL OIL				PROPANE	PROPANE	PROPANE
BACKUP ENERGY SOURCE		BLR. STM.											
NON RECYCLE SYSTEM		✓	✓	✓	✓	✓	✓				✓	✓	✓
PARTIAL RECYCLE SYSTEM								20%	20%	20%			
FULL RECYCLE SYSTEM													
UNCONTROLLED SYSTEM:	LBS/HR												
	gr/SDCF				0.631	0.644	1.522						
	OPACITY (%)	0			100	100	100						
CONTROLLED SYSTEM:	WET SCRUBBER												
	FULL RECYCLE												
	PARTIAL RECYCLE												
	MED. EN. SECONDARY CYC.										✓	✓	✓
	MULTIPLE CYCLONES		✓	✓									
	FABRIC FILTER												
	OTHER	CYCLONE						SKIMMER	SKIMMER	SKIMMER			
COST OF CONTROLLED SYSTEM:	CAPITAL (1000 $)	100									82	82	82
	OP. EXPENSE (1000 $)												
	ANNUAL MAINTENANCE ($)												
ENERGY REQUIREMENTS: (HORSEPOWER)		50	200	200				50	50	50	150	150	150
CONTROLLED EMISSIONS:	gr/SDCF			.028							7 LBS/HR	7 LBS/HR	7 LBS/HR
	OPACITY (%)							0	0	0	0	0	0
EMISSION TEST METHOD:	HI-VOLUME			✓	✓	✓	✓						
	EPA METHOD 5												
	S - 8 VENEER DRYER												

DRYER NO.	73	74	75	76
PROCESS: HARDBOARD (FIBERS)	✓	✓	✓	✓
PARTICLEBOARD (PARTICLES)				
DRYER TYPE: TUBE (INLINE)	✓	✓	✓	✓
FLASH				
STATIONARY DRUM				
ROTARY SINGLE PASS DRUM				
ROTARY TRIPLE PASS DRUM				
DRYER SYSTEM: SINGLE DRYER				
1st DRYER IN SERIES	✓	✓		
2nd DRYER IN SERIES			✓	✓
YEAR INSTALLED:	1960	1960	1965	1965
FURNISH: SURFACE	HOMO.	HOMO.	HOMO.	HOMO.
CORE				
MATERIAL FEED RATE (LBS/HR DRY BASIS)	12,000	12,000	12,000	12,000
INLET MOISTURE (%)	50-80	60-80	25-40	25-40
EXIT MOISTURE (%)	25-40	25-40	6	6
INLET GAS TEMP. (°F)	600	600		
EXIT GAS TEMP. (°F)			120-200	120-200
EXIT GAS FLOW RATE (ACFM x 1000)	18	18		
MOST COMMON SPECIES	HARDWOODS	HARDWOODS	HARDWOODS	HARDWOODS
MATERIAL SIZE RANGE	< 3/4"	< 3/4"	< 3/4"	< 3/4"
PRIMARY ENERGY SOURCE	NO. 6 OIL	NO. 6 OIL	NO. 6 OIL	NO. 6 OIL
SECONDARY ENERGY SOURCE				
BACKUP ENERGY SOURCE				
NON RECYCLE SYSTEM	✓	✓	✓	✓
PARTIAL RECYCLE SYSTEM				
FULL RECYCLE SYSTEM				
UNCONTROLLED SYSTEM: LBS/HR	14	14	17	17
gr/SDCF				
OPACITY (%)	0	0	0	0
CONTROLLED SYSTEM: WET SCRUBBER				
FULL RECYCLE				
PARTIAL RECYCLE				
MED. EN. SECONDARY CYC.				
MULTIPLE CYCLONES				
FABRIC FILTER				
OTHER				
COST OF CONTROLLED SYSTEM: CAPITAL (1000 $)				
OP. EXPENSE (1000 $)				
ANNUAL MAINTENANCE ($)				
ENERGY REQUIREMENTS: (HORSEPOWER)				
CONTROLLED EMISSIONS: gr/SDCF				
OPACITY (%)				
EMISSION TEST METHOD: HI-VOLUME	✓	✓	✓	✓
EPA METHOD 5				
S - 8 VENEER DRYER				

APPENDIX E

PARTICLEBOARD AND
MEDIUM-DENSITY FIBERBOARD
MANUFACTURING PLANTS

1. Giles & Kendall, Incorporated
   Maysville, AL

2. Louisiana Pacific Corporation
   Post Office Box 246
   Clayton, AL 36016

3. Louisiana Pacific Corporation
   Eufalla, AL

4. MacMillan Bloedel Particleboard, Incorporated
   Pine Hill, AL

5. Olinkraft, Incorporated
   Monroeville, AL

6. Southwest Forest Industries, Incorporated
   Box 1809
   Flagstaff, AZ 86001

7. Georgia Pacific Corporation
   Post Office Box 520
   Crossett, AR 71635

8. International Paper Corporation
   Post Office Box 610
   Malvern, AR 72104

9. Singer Company
   Main Street
   Trumann, AR

10. Wynnewood Products Company
    Division of Permaneer Corporation
    Post Office Box 685
    Hope, AR 71801

11. American Forest Products
    Highway 49
    Martell, CA 95654

12. Big Bear Board Products
    Division of Golden State Building Products
    Box 1028
    Redlands, CA 92373

13. Champion International
    Box 2317
    Redding, CA 96001

14. Collins Pine Company
Box 796
Chester, CA 96020

15. Fibreboard Corporation
4300 Dominguez Road
Rocklin, CA

16. Georgia Pacific Corporation
2163 North State Street
Ukiah, CA 95482

17. Hambro Forest Products
Post Office Box 129
Crescent City, CA 95531

18. Humboldt Flakeboard
Drawer CC
Arcata, CA 95521

19. Louisiana Pacific Corporation
Arcata, CA

20. Sequoia Board, Incorporated
Post Office Box 906
Chowchilla, CA 93610

21. Georgia Pacific Corporation
Box 187
Vienna, GA 31092

22. Temple Industries, Incorporated
Thompson, GA

23. Weyerhaeuser Company
Box 547
Adel, GA 31620

24. Potlatch Forest Corporation
Post Office Box 786
Post Falls, ID 83854

25. Swain Industries, Incorporated
1001 West Second Street
Seymour, IN 47274

26. Tenn-Flake Corporation
Industrial Park
Middlesboro, KY 40965

27. Duraflake South, Incorporated
Division of Willamette Industries, Incorporated
Simsboro, LA 71275

28. Louisiana Pacific Corporation
Box 26
Urania, LA 71480

29. Olinkraft Particle
Lillie, LA 71256

30. Champion International
Gaylord, MI 49735

31. Blandin Wood Products Company
Box N
Grand Rapids, MN 55744

32. Cladwood Company
Division of Forest Products Sales Company
Box 3
Virginia, MN 55792

33. Champion Internation
Route 7-N
Oxford, MS 38655

34. Georgia Pacific Corporation
Box 309
Louisville, MS 39339

35. Georgia Pacific Corporation
Box 627
Taylorsville, MS 39168

36. Kroehler Manufacturing Company
Box 4176, West Station
Meridian, MS 39301

37. Evans Products, Incorporated
Drawer L
Missoula, MT 59801

38. Plum Creek Lumber Company
Post Office Box 160
Columbia Falls, MT 59901

39. Ponderosa Products, Incorporated
1701 Bellamah, N.W.
Box 813
Albuquerque, NM 87103

40. Carolina Forest Products, Incorporated
King Street
Wilmington, NC 28402

41. Evans Products, Incorporated
Box 168
Moncure, NC 27559

42. Georgia Pacific Corporation
Box 727
Whiteville, NC 28472

43. International Paper Company
Box 229
Farmville, NC 27828

44. Nu-Woods, Incorporated
747 Harrisburg Drive, S.W.
Lenoir, NC 28645

45. Permaneer Corporation
Division of Wynnewood Products Company
Box 756
Black Mountain, NC 28711

46. Surecore Corporation
(formerly Ward Industries, Incorporated)
2400 Industrial Park
Miami, OK 74354

47. Weyerhaeuser Company
Division of Craig Box
Craig Plant, Highway 70
Broken Bow, OK 74728

48. Bohemia, Incorporated
Particleboard Division
50 North Danebo Avenue
Eugene, OR 97402

49. Boise Cascade Corporation
Post Office Box 1087
LaGrande, OR 97850

50. Brooks-Willamette Corporation
(Affiliate of Willamette Industries, Incorporated)
Hill Street
Bend, OR 97701

51. Publisher's Paper Company
Philomath, OR

52. Duraflake Company
Division of Willamette Industries, Incorporated
Old Pacific Highway
Albany, OR 97321

53. Fibreboard Corporation
Clear Fir Products Division
1116 South A Street
Springfield, OR 97477

54. Medford Corporation
North Pacific Highway
Medford, OR 97501

55. Permaneer Corporation
Division of Forest Products Industries, Ltd.
Dillard Garden Road
Dillard, OR

56. Permaneer Corporation
Division of Forest Products Industries, Ltd.
Post Office Box 178
White City, OR 97501

57. Roseburg Lumber Company
Highway 99
Roseburg, OR 97432

58. Timber Products Company
McAndrews Road
Medford, OR 97501

59. Weyerhaeuser Company
Post Office Box 9
Klamath Falls, OR 97622

60. Weyerhaeuser Company
Wood Products Division
Post Office Box 275
Springfield, OR 97477

61. Georgia Pacific Corporation
Russellville, SC 29476

62. Georgia Pacific Corporation
Sumter, SC

63. Holly Hill Lumber Company
Box 128
Holly Hill, SC 29059

64. International Paper Company
Southern Kraft Division
Box 3189
Greenwood, SC 29646

65. Tenn-Flake Corporation
2525 Trade Street
Morristown, TN 37814

66. Kirby Lumber Company
Post Office Box 1566
Silsbee, TX 77656

67. Louisiana Pacific Corporation
Corrigan, TX 75939

68. Permaneer Corporation
Division of Wynnewood Products Company
Box 1088
Jacksonville, TX

69. Temple Industries, Incorporated
Diboll, TX 75941

70. Champion International
Drawer 250
South Boston, VA 24592

71. Masonite Corporation
West Main Street
Waverly, VA 23890

72. Union Camp Corporation
Edgehill Drive
Franklin, VA 23851

73. International Paper Company
Longbell Division
Box 579
Longview, WA 98032

74. Rodman Industries
Resinwood Division
Box 76
2601 Cleveland Avenue
Marinette, WI 54143

75. Weyerhaeuser Company
1401 East Fourth Street
Marshfield, WI 54449

APPENDIX F

HARDBOARD MANUFACTURING PLANTS

1. Chicago Hardboard
   2561 West Madison
   Chicago, IL

2. Abitibi Corporation
   416 Ford Avenue
   Alpena, MI

3. Boise Cascade Corporation
   Second Street
   International Falls, MN 56649

4. Superwood Corporation
   Post Office Box 518
   Bemidji, MN 56601

5. Superwood Corporation
   1400 West W and Waterfront
   Duluth, MN 55802

6. Celotex Corporation
   Subsidiary of Jim Walter Corporation
   Laurel Bank Avenue
   Box 67
   Deposit, NY 13754

7. Georgia Pacific Corporation
   Box 348
   Conway, NC 27820

8. Masonite Corporation
   U.S. 64
   Springhope, NC 27882

9. Weyerhaeuser Company
   Moncure, NC 27559

10. Georgia Pacific Corporation
    Hardboard Division
    Post Office Box 869
    Coos Bay, OR 97420

11. Pope & Talbot
    Box 426
    Oakridge, OR 97463

12. U.S. Plywood
    Division of Champion International
    Post Office Box 547
    Lebanon, OR 97355

13. Weyerhaeuser Company
Post Office Box 9
Klamath Falls, OR 97601

14. Masonite Corporation
Box 311
Towanda, PA 18848

15. Celotex-Sellers Corporation
Marion, SC

16. Champion International
Catawba Manufacturing Division
Box 66
Catawba, SC 29704

17. Celotex Corporation
Route 4, Box 1090
Paris, TN 38242

18. Temple Industries, Incorporated
Diboll, TX 75941

19. Evans Products, Incorporated
Box 135
Doswell, VA 23047

20. Evans Products Company
Fiber Products Division
Philips, WI 54555

APPENDIX G

PLANTS WHOSE PRODUCTS ARE NOT VERIFIED

1. American Forest Products
Stockton Box Plant
Forest Hill, CA 95631

2. Fiberite West Coast Corporation
690 North Lemon
Orange, CA

3. Georgia Pacific Corporation
Lenore and Commercial Streets
Willits, CA 95490

4. Louisiana Pacific Corporation
Oroville, CA

5. U.S. Plywood
Post Office Box 2317
Anderson, CA

6. Pack River Company
Dover, ID

7. Georgia Pacific Corporation
Route 38
Evarts, KY

8. International Paper Company
Box 37
Wiggins, MS 39577

9. Georgia Pacific Corporation
Box 507
Ahoskie, NC 27910

10. Georgia Pacific Corporation
Box 666
Enfield, NC

11. Georgia Pacific Corporation
Plymouth, NC

12. Masonite Corporation
Box 459
Thomasville, NC 27360